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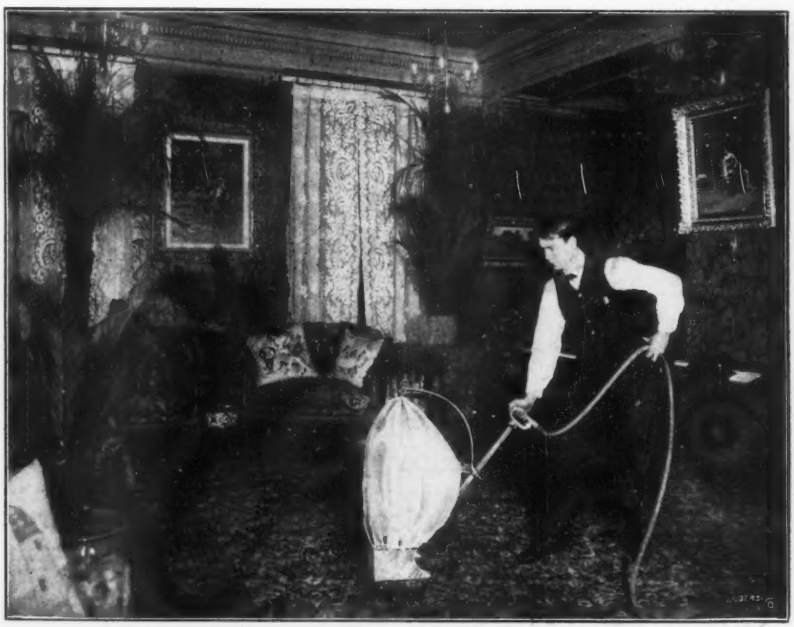
VOL. VI. NEW YORK, APRIL, 1901. No. 2.



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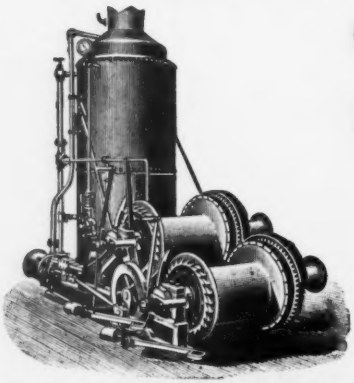

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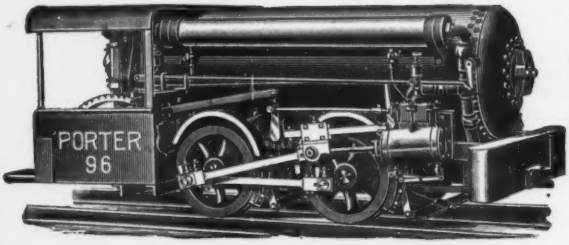

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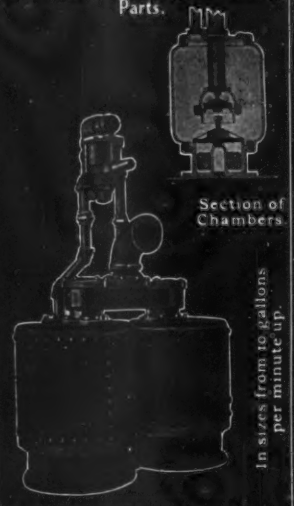

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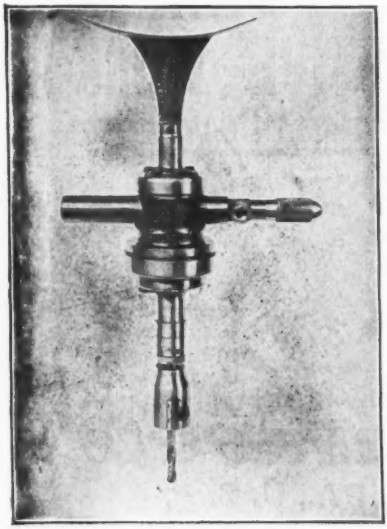

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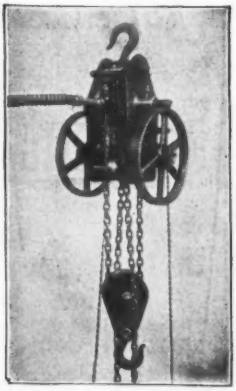

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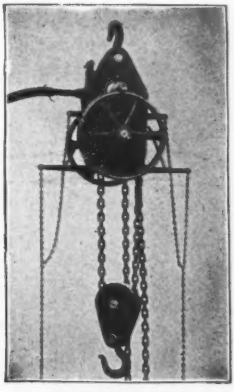

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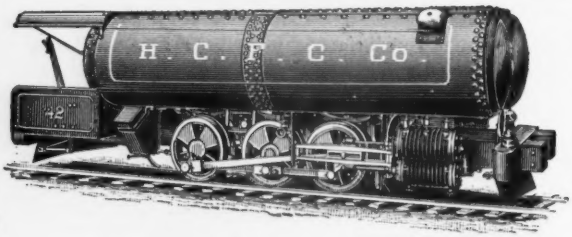

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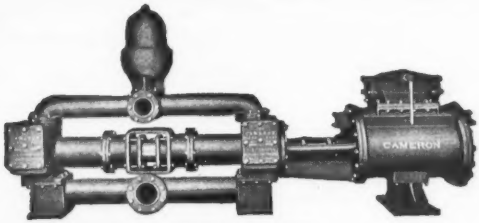

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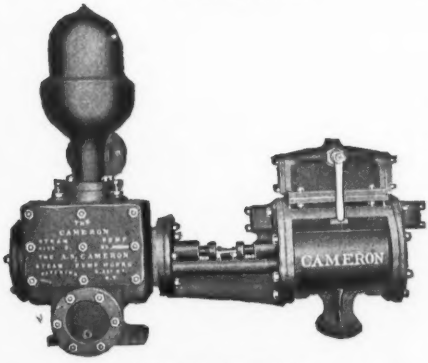

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VOL. VI. APRIL, 1901. NO. 2.

The New York Herald recently reported the result of a conference held in Washington between the Illinois Manufacturers and the Secretary of the Treasury as follows:

"In a statement prepared by the Secretary it is shown that the export value of articles affected wholly or in part by the Russian decree is $2,872,429, instead of $11,000,000, as has been reported. The export value of articles not affected by the Russian retaliatory measures is $7,598,020."

This effort on the part of the Treasury Department to minimize the importance of the recent revolutionary order imposing a countervailing duty on Russian sugar has led us to investigate the United States statistics of export.

Any one familiar with the general run of our export business will observe some errors when looking over the figures issued from Washington. Take the following:

Our imports from Switzerland,
1899-1900 ..... $17,393,268
Our exports to Switzerland,
1899-1900 249,727

When comparing the export figure issued from Washington with the corresponding import figure issued by the Swiss Government, it turns out that our exports to Switzerland are not much less than our imports from there, so there must be a grave error either on the part of our own statisticians or the part of the Swiss, which error is repeated year after year, ever since our statistics have embraced the subject of foreign trade.

Further discrepancies may be found in the official report figures given for several other European countries though in these cases the errors are not so striking.

It is true that the export statistics are built up on the statements (clearances) given by the export merchants and these statements being each one sworn to, are fairly reliable so far as they go—but the error comes in in connection with the printed wording of the clearance blanks. The printed heading of these blanks gives to the exporter a guide as to what data are required to be filled in under the heading of the respective columns. If the heading calls for the mark and number the exporter knows that the marks and numbers of the cases are to be inserted in the respective column. Just so when the heading calls for the contents of the cases and for the value of the goods. Again, when the heading reads: "To be landed at," the merchant knows what he has to fill in, viz: the name of the port where the goods are to be landed. That is precisely what the merchant does, when making out his clearance, and there is where the mistake comes in, Switzerland has no seaport, so if goods are shipped for Switzerland the exporter will clear them

as going to Antwerp and when the customhouse clerks come to compile their returns that shipment will be classed in under the heading of the "Exports to Belgium." The exporter has given his clearance correctly, so far as he could be expected to, to comply with the printed requirements of the clearance blank; the customhouse clerk made his returns correctly so far as he could on the basis of the clearances sworn to by the exporters. Still the result is a blunder.

The officials of the customhouse do not go entirely by the landing place put down in the clearance. If the "mark" as appearing in the clearance gives any clue to the final destination, they go by that clue and class the goods for the respective country. So if the shipment should be marked "A. S-Zurich" the customhouse officials will class that shipment as going to Switzerland. This is the reason why Switzerland is not altogether ignored in the export column of the United States. To some extent they also go by the bill of lading. If the latter is a so-called "through bill of lading," for instance, if it reads that the goods are to go "via Hull through to Odessa," the customhouse clerk will credit that shipment not to England but to Russia. In consequence, at least a part of the shipments going to Russia are classed as such.

To make sure of the facts an exporter had some shipments for one and the same consignee marked in different ways. The one shipment was marked, "A. B. Cologne," the other shipment was just marked, "A. B." When tracing these cases in the regular statements published by the Journal of Commerce, he found the one lot under the heading of "Shipments to Cologne," the other lot under "Shipments to Rotterdam." When compiling his returns the customhouse clerk naturally credited the one shipment to Germany, while the other went as "exports to Holland," though both went to the city of Cologne.

Following up the general principle that shows forth in the above data, it is clear that such countries as have direct steamer connection with the United States are put down as receiving much more of our goods than they really do and appear as much larger customers of the United States than the facts warrant. Thus, Great Britain appears to take an enormous proportion of our total exports to Europe, but the figure given for the last year of $527,000,000 would dwindle down considerably if all shipments were deducted that merely touch Great Britain and are really intended for other countries. On the same principle the figure of $89,000,000, given as our exports to Holland, would lose by far the greater part when deducting the shipments which are merely passing through that country and are really intended for Germany. Just so the figure of $47,000,000 given for "exports to Belgium" would be cut down when deducting the shipments for Switzerland and for the south of Germany.

Now let us apply the point above brought out to our present tariff imbroglio with Russia. The Government figures of exports to European Russia for the year 1899-1900 are understated as numerous shipments go to that country by way of England, Denmark or Germany that never appear in our statistics under the heading of "Exports to Russia." A large portion of the goods intended for Russia go to Hamburg, not on a "through" but on a port bill of lading, and is transshipped from Hamburg either by rail or by steamer—a fact that is true much more in articles of manufacture like steel and iron goods, than in staples like cotton, etc.

Russia is an inland country, with only two or three seaports and only one, Riga, an open port, in the winter months. There are no direct lines of steamers be-

tween the United States and Russia, hence goods are shipped to other countries and reshipped into Russia.

An exporter has at present in New York an order for steam engines bought through a London house with orders to ship to Liverpool. There is every reason to believe that these engines are to be used in Russia, as the London house is the financial end of a Russian concern, yet their orders are to ship to Liverpool, where it is more convenient to make up a cargo for shipment to Russia.

Another point is that Russian ways of doing business and Russian credits are not known to American merchants. Business is done in Russia usually on six months' time and there is a good deal of uncertainty about credits there. A Russian concern buying machinery requires the seller to furnish a guarantee made by a home bank that he will fulfill his contract. Such handicaps affect business and induce American merchants to deal through English, Belgium, German and other houses which have connections in Russia and better facilities for doing business there. Most of these goods are marked as products of America, hence, they pay the Russian tariff against American goods, but some of them, such as small articles of hardware, have their origin lost entirely.

The main point is that the United States Government statistics of export are only accurate in the grand total, but when such total is analyzed and divided into exports to different countries, the figures cannot be accepted. A nation's statistics of imports are always more reliable than those of export for reasons that are obvious.

House Cleaning.

We illustrate on our cover the apparatus of the General Compressed Air House Cleaning Company, St. Louis, Mo. By this system they clean the walls of all dirt and dust, thoroughly renovate the carpet, removing and collecting all dust and dirt contained in it, and also that between the carpet and the floor. After cleaning, the carpets are disinfected,the disinfectant being blown on the walls and into the carpet by compressed air. By this system the cost is greatly reduced, and the rooms, including all articles of furniture, are thoroughly cleaned.

The air is furnished by an automatic air compressor mounted in a wagon, the compressor being operated by a 15 h. p. gasoline engine, and the air being compressed to 100 lbs. A rubber hose is run from the wagon into the house Air is also furnished by being compressed to 2,500 lbs. or 3,000 lbs. and stored in steel tubes at the factory, which can then be delivered at the house. For large hotels and apartment houses individual plants are installed, as there is cleaning going on at all seasons of the year.

With this apparatus, it is claimed that one man can clean from eight to twelve rooms per day, including walls and all furniture.

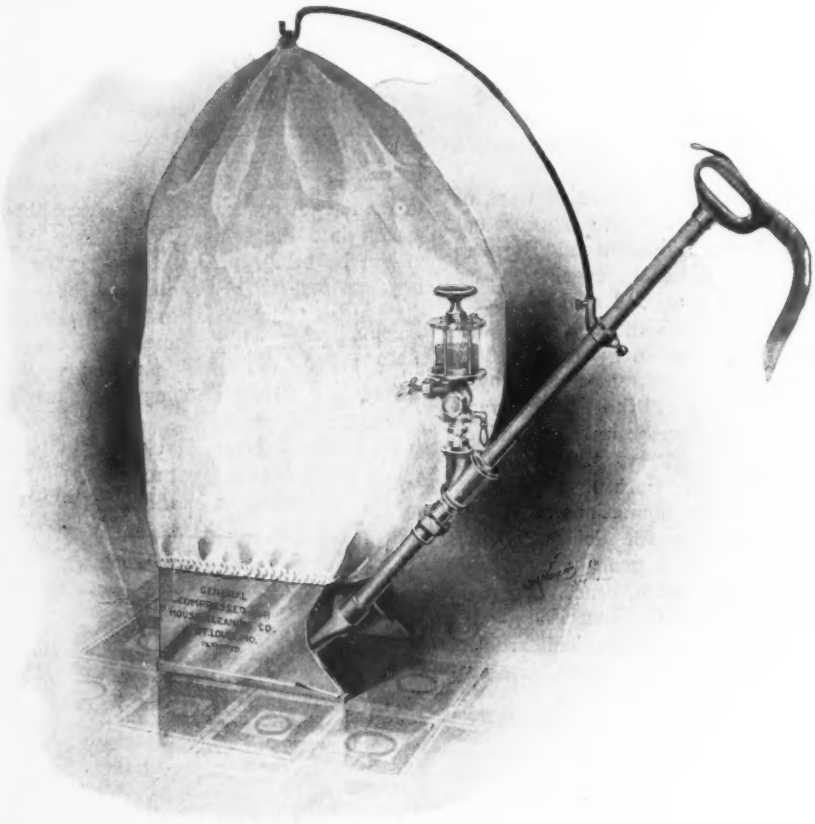
Portable Pneumatic Tools.

PART II.

EWART C. AMOS, M. I. M. E.

The many advantages to be derived from the application of compressed air for the purpose of driving portable drills are probably more apparent than in the case of either hammers or riveters. In the author's opinion, the portable pneumatic drill, with its many applications, will soon be recognized (if it is not already) as one of the most important additions that have been made in recent times to our stock of labor-saving machines. A great deal of work, which for economic reasons had before to be drilled in the shop previous to erection, can now be drilled in sitû, and the result, besides being more satisfactory in itself, has considerably reduced the cost. Besides drilling, portable pneumatic drills can be used for reaming, tapping, tube expanding,

cleaning castings, boring wood, screwing nuts on to bolts, boring cylinders and Corliss valve seats, grinding steam-pipe joints, turning up crank and car-wheel pins in position, and a variety of other purposes which will readily suggest themselves. The method by which compressed



GENERAL COMPRESSED AIR HOUSE CLEANING CO.'S APPARATUS, ST. LOUIS, MO.

air is utilized for driving the drills is generally by means of single or double-acting cylinder motors, the cylinders of which are sometimes fixed and sometimes oscillating and these again actuate suitable mechanism for driving the bit, and are encased in the body of the drill. The

piston air-drill, as it may conveniently be termed, has become a very important factor in boiler work, shipbuilding and constructional work generally. As a reamer or tube expander the saving over hand-labor is very great, and at the same time the work is turned out much faster—a great point in shipbuilding. Pneumatic drills are made in a large number of sizes, from light drills suitable for small holes up to powerful ones developing two to three horse-power. The latter are capable of driving bars for boring work in position, or re-turning crank-pins, etc., and

their range of usefulness is very large. They can be worked economically with 60 to 80 lbs. of air pressure.

Plate II shows several standard types of pneumatic drills, and the following figures give sections and details affording a clear idea of the general construction of each type. Fig. 16 is a longitudinal sectional elevation of a "Little Giant" portable air-drill, taken on lines 1-1 of Fig. 17. In this type of drill the motor consists of four single-acting cylinders arranged in pairs, and having each pair of pistons connected to opposite ends of a double crank-shaft. The pistons of each pair travel in opposite directions at all parts of the stroke to effect smooth running. The cylinders are controlled by balanced piston-valves set to cut off at 5-8ths of the stroke, and should therefore prove economical. Referring to Figs. 16-17, A is the main casing, which contains the mechanism; B and B^1 are one pair of cylinders, and C and C^1 the other, and arranged at right angles to each other and connected to a common crank-shaft D. By this arrangement a dead centre is avoided. The air admission and exhaust is controlled by two piston valves E and E^1. These are worked by small eccen-

TABLE No. 2.

COMPARISON OF COST BETWEEN MACHINE AND HAND-RIVETING AT CHICAGO SHIPYARDS.

(Taken during three weeks ending 12 October, 1899.)

Distribution.	Number of Rivets.	Diam. of Rivets.	Machine Rate each.	Hand Rate each.
		Inch.	Cents.	Cents.
Keel	6,217	1	2½	4½
Shell	21,628	⅞	1¾	3½
Shell Margin (bilge single line)	1,122	⅞	3	4½
Longitudinals open	24,632	¾	1¼	2¾
C. V. K. Brackets	3,197	¾	1	3½
" "	—	—	1¼	3½
" "	—	—	1½	3½
Longitudinals under tank	664	¾	1¾	2¾
Longitudinal bars	2,989	¾	1¼	2¾
Tank-top Stiffeners	1,129	¾	2½	3½
Tank-top Margin	4,033	¾	1½	2¾
Tank-top Lugs	1,520	¾	1¾	3½
Tank-top Rider	3,209	¾	1¼	2¾
Tank-top	4,467	¾	1¼	2¾
C. V. K. Cross Vertical Kelson	12,723	¾	1	3
Hold Stringer	1,184	¾	1½	3
Floors	123	¾	1¼	3
Floors (odd)	5	¾	2	6
C. V. K. (odd)	38	¾	2	6
Bulkheads	1,318	¾	1¼	5
"	3,051	¾	1¾	3¼
"	231	⅝	1½	2½
Total	93,480			

Total cost by machine, $1,403.31. Average 1.50 cents each.
Total cost by hand would have been $2,986.87. Average 3.19 cents each.
Saving $1,583.56. Average 1.09 cents each.
Average cost of machine riveting was 47 per cent. of hand cost.

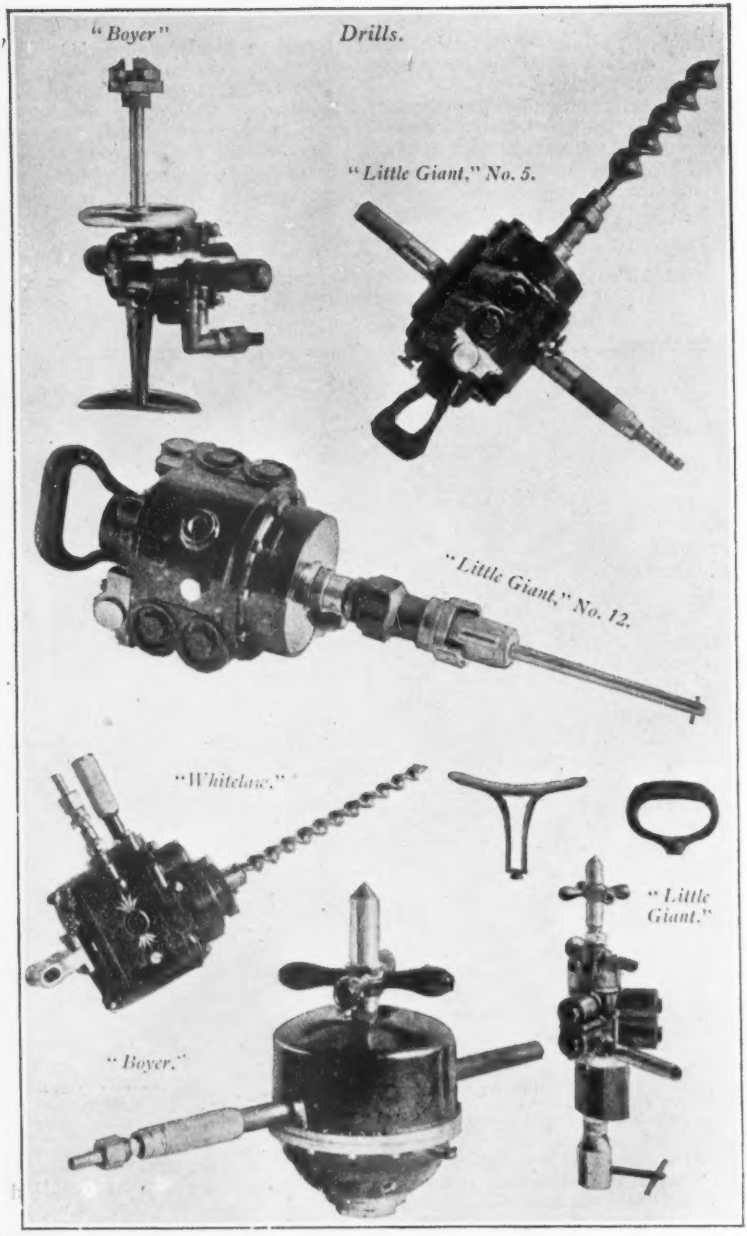


PLATE II.—TYPES OF PNEUMATIC DRILLS.

trics off the crank-shaft, and serve to control the four cylinders; f is the main pressure chamber, having communicated with the supply pipe H. They are reduced in diameter in the centre, and are hollow. The arrows show the direction taken by the air. Cylinders B and B^1 receive air-communications through f^2 and f^3, and cylinders C and C^1 through c^3 and c^4, the exhaust taking place through the interior of the two valves. The action is as follows: f is full of live air which is blowing through c^4 and f^3, to supply cylinders C^1 and B^1, whilst cylinders B and B^1 are exhausting through f^2 and c^3 into the centre of the valves and thus to the atmosphere. Referring to Fig. 16, k and k^1 are gear wheels by which the rotary motion of the crank-shaft is conveyed to the part K, which is fitted with a suitable drill holder or chuck. L is a threaded sleeve, which, in conjunction with L^1 and other parts, provide for the feeding down of the drill. This tool is also furnished with a simple reversing arrangement, which enables it to do all classes of work for which a drill is suitable; for this it is fitted with a handle in the place of the star centre. By revolving this handle a valve placed in the main pressure chamber reverses the direction taken by the air when entering the valve bushing, suitable ports being provided. The drill is thus capable of dealing with work, where reversing is necessary, as in tapping, tube expanding, wood boring, etc. Pneumatic drills of this description are now used at the carriage department of the London and North Western Railway Works at Wolverton driving saw-bits for the purpose of cutting out the lamp holes and openings for the heating apparatus in railway carriages. This is the first application of its kind.

Fig. 18 shows the interior of a "Whitelaw" drill with half the casing removed, whilst Fig. 19 shows the passage of the air leading to the cylinder and the method of reversal. This type of drill is actuated by two double-acting oscillating cylinders A and B, driving a crank-shaft C, to which is attached a pinion D driving the gear wheel E, attached to the drill spindle. Its action is therefore at once seen, and reference to the cross section, Fig. 19, will show that by rotating the milled handle F, which gears into a short rack G at the end of the lever H, the hollow portion I changes its position, with the result that reversal takes place in the usual way adopted in oscillating cylinders. The exhaust is made into the casing and escapes through suitable apertures. The reversal is instantaneous, and the machine is well adapted for all kinds of drilling, tapping, tube expanding, wood-boring, etc., the

TABLE No. 3.

PNEUMATIC DRILLS.

Type.	Descriptive Number.	Weight.	Revolutions per minute, machines unloaded.	B. H. P.	Air-Consumption in Free Air.	Maximum Duty.
		lbs.			Cub. ft. per min.	
"Little Giant." Figs. 21 to 23.	0	45	125	2¼	45	3" holes in metal.
	1	35	190	1½	35	2" " " "
	2	19	250	1	25	1¼" " " "
	3	8	750	..	15	½" " " "
"Whitelaw." Figs. 26 and 27.	4	..	1,000	¼	15	¼" " " "
	6	14	720	¾	20	3" holes in soft wood
	7	20	250	1	25	For tube expanding.
	8	39	120	1½	30	3" holes in metal.
"Boyer." Figs. 28 to 30.	2	46	180	1¼	30	3" " " "
	3	41	240	1	25	1" " " "
	6	17	500	¾	20	¾" " " " 3" holes in soft wood

reversing arrangement especially lending itself for such purposes. The machine is supplied with ample lubrication, and is fitted with ball bearings throughout.

Fig. 20 illustrates a transverse vertical section of a "Boyer" piston drill, and Fig. 21 is a horizontal section taken through the centre of the cylinders. The machine consists of three main parts: (1) The upper housing into which the throttle valve and steadying handle are screwed, and which forms a live-air chamber carrying the motor; (2) The diaphragm which forms the lid or cover of the upper housing or live-air chamber, and through which the hollow exhaust spindle projects; (3) The lower housing secured to the upper housing by means of screws, and containing the gear wheel rack, bearings for drill spindle, etc. The motor is in the form of a three-cylinder single-acting oscillating engine, the cylinders being

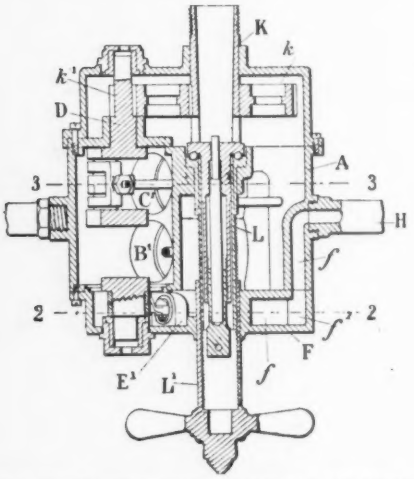


FIG. 16.—"LITTLE GIANT" PORTABLE AIR-DRILL. LONGITUDINAL SECTION.

carried in the rotary frame. This frame consists of an upper and lower plate, and is triangular in shape and is free to revolve round its centre on two bearings, the lower one being a hollow shaft, and connected by gearing to an internally toothed wheel in the lower half of the casing. The admission of air to the cylinders is regulated by the valves formed in the pivots upon which the cylinders oscillate. The cylinders are single acting, and the inner ends are open, and therefore air under pressure, of which the upper casing is always full, has free access to the pistons on that side. It would seem, therefore, that air being admitted through the pivot valves would only produce equilibrium, but since one of the cylinders is always open to the exhaust through the hollow bearing of the triangular frame, this equilibrium becomes disturbed, and the compressed air has full effect upon each piston as the valve comes in line with the exhaust. The cylinders are constructed of steel tubes, and are fitted with trunk pistons having their connecting-rod ends attached to a fixed crank-pin common to them all;

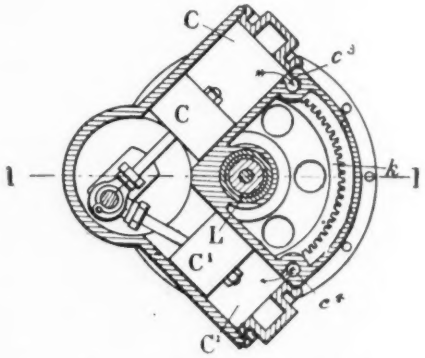


FIG. 17.—"LITTLE GIANT" PORTABLE AIR-DRILL.

the pistons having been set in motion by the introduction of compressed air into the upper casing, and into the cylinder as already described, has the effect of causing the three cylinders, together with their triangular framing, to rotate round the fixed crank-pin, and thus transmit rotary motion to the spindle by means of the gearing before referred to. This class of machine is fitted with a regulator by means of which the power and speed of the drill can be varied as desired.

Figs. 21, 22, and 23 illustrate the "Little Giant" high-speed rotary drill, which consists of a casing C containing three rotating cylinders F, each of which is governed by a piston slide valve E. These valves rotate with and work in cylinders or valve chambers forming part of the main engine cylinders F. In other machines for effecting the same and similar purposes the casing is used as a live air

chamber; in the "Little Giant" type it is used as an exhaust receiver. Again, in other machines the air has been directly admitted into the casing C or live air chamber, whereas with the "Little Giant" drill it is carried through a separate channel from the supply pipe A, and through a stationary or fixed hollow crank-shaft B, into a passage L, leading to the reduced portions of the piston slide-valves E, and according to the position of such valves admitted to, or exhausted from the cylinders F. It will also be noticed that in the "Little Giant" drill the exhaust does not blow through the gear mechanism, since it is so arranged that it is admitted into the main casing C, which is itself hermetically sealed from the lower portion of the machine which contains the reducing gear, so that the exhaust passes out through a separate pipe K.

The leading feature in the "Little Giant" machine is that it combines a high-speed engine with a low consumption of air, and this result has been obtained by employing a stationary eccentric D, which is set at the required point in the throw of the crank-shaft to obtain the necessary cut-off, the cylinders F, and their governing slide-valves E, rotating about this eccentric. As is well known, in engines of this type the travel of the eccentric should be quickest when the motion of the piston is slowest, and this is provided for in the present design by having a very quick port opening and an equally quick release, thus enabling the rotating cylinders to move at an exceedingly rapid rate, the air not having to travel through tortuous passages either in or out. With other engines of this character, especially with engines of the oscillating type, where the valve motion is slowest when the piston is on the centre or at the end of its stroke this condition does not exist.

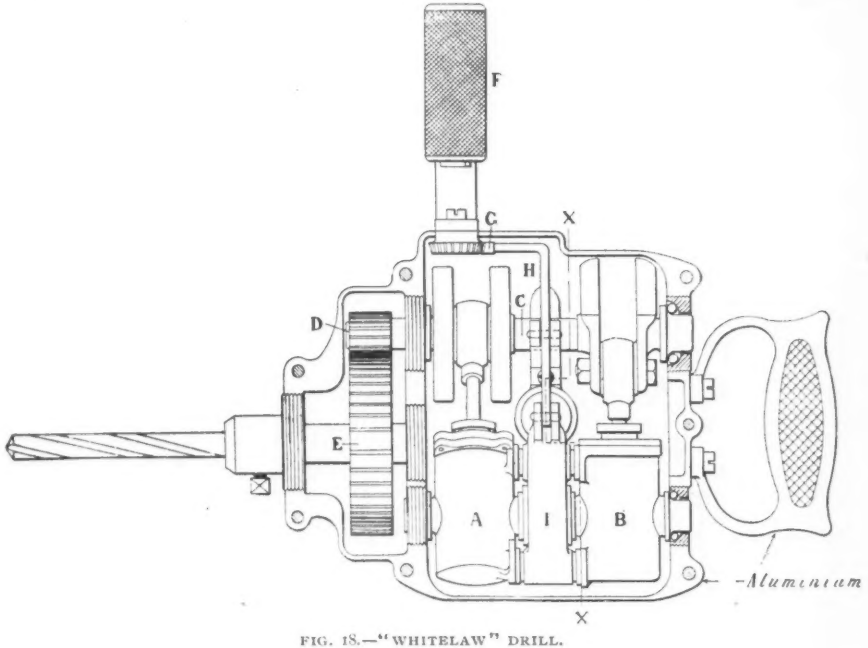


FIG. 18.—"WHITELAW" DRILL.

Table 4, referred to by the author, gives results of work done with various types of pneumatic tools. Briefly, this indicates that each hammer for calking and general purposes will do the work of from two to three men, although some reports run up as high as to six times the amount of one man.

Riveters were reported effective and

economical. Drills, far superior to hand methods and most satisfactory.

Other Pneumatic Appliances.—Air-Hoists.—Having put down a system of compressed-air supply for the purpose of driving hammers, drills and riveters, it soon becomes evident that such supply may be employed for other purposes; and one of the most useful applications that can be made is for working air-hoists. These are now coming into extensive use in this country, and there is every indication that before long few shops will be

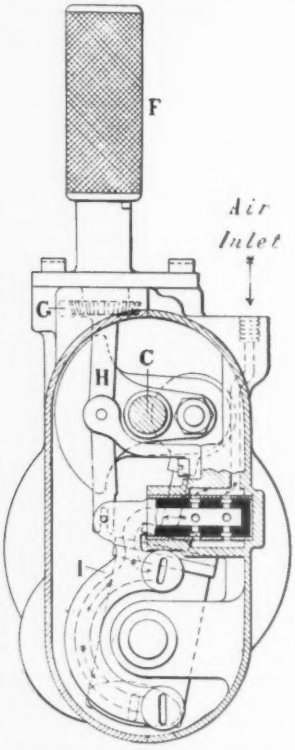


FIG. 19.—"WHITELAW" DRILL.

without them. The economy effected, when they are fitted up on a light jib and suspended over a lathe or other tool, is very considerable, and they save both time and labor. As is well known, much delay is experienced in lowering the ordinary chain blocks, even when unloaded, whilst with an air-hoist this operation is rapidly effected. The load can also be more readily brought into position as the adjustment is very sensitive. The difference between one make of hoist and another lies chiefly in the system of valves and also in respect to the material used for the cylinder. For the latter some makers use cast iron, others wrought iron, and others again use brass. Some hoists have only one valve, this kind being used for quick work, and when it is not desired to keep the load accurately suspended for any length of time. This valve is either an ordinary opening and closing valve operated by the hand chain, or it may be a valve to automatically close when the chain is released when either raising or lowering the load. Another type of valve provides for the admission

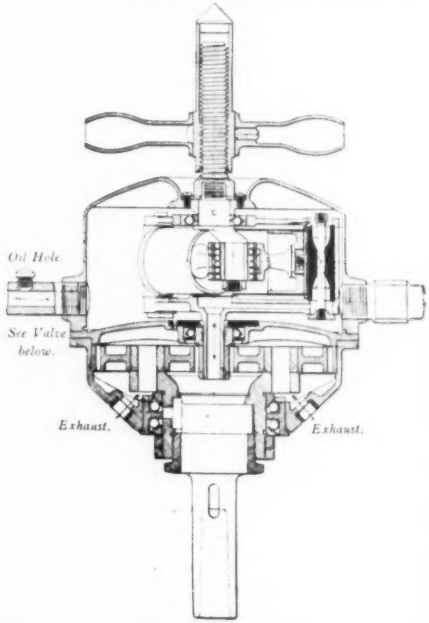


FIG. 20.—"BOYER" PISTON AIR-DRILL. VERTICAL SECTION THROUGH CENTER OF MACHINE.

and release of the air in the cylinder, and is left open for supply when lifting the load; working in conjunction with this valve and controlled by the piston-rod is another valve, which automatically closes the air-supply when any desired level is reached; at the same time should there be any leakage of air, it re-admits automatically just sufficient air to maintain the load at a constant level. When, however,

it is desired to maintain in a stationary position a varying load, such as a foundry ladle, a third valve is introduced. It may be stated that a 5-inch straight lift hoist will lift 10 to 11 cwts. with 75 lbs. air-pressure. Hoists, such as have been described, may be simply suspended, or they can be mounted on a trolley and light jib for ordinary shop use to serve lathes and other tools. Or, again, they may serve the whole length of a shop by causing the trolley to run on a fixed over-head girder. The same principle may also be applied for the purpose of lifting in almost every kind of crane, and for foundry and shop use they are likely to have considerable application.

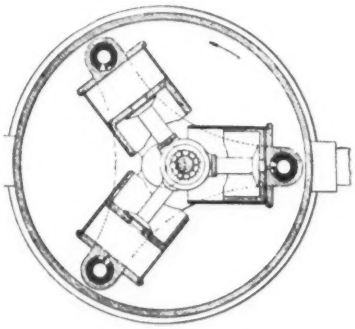


FIG. 21.—"LITTLE GIANT" DRILL. HORIZONTAL SECTION THROUGH CENTER OF CYLINDERS.

Pneumatic Chain Hoists.—When it is desired to use a chain hoist, for want of head room or length of lift, in preference to a straight lift hoist, and at the same time to obtain a portable lifting device, this may be secured by using an ordinary chain hoist in combination with a reversible rotary pneumatic motor.

Pneumatic Jacks.—These may also be termed inverted hoists. They act on the same principle, and where an air-supply exists they are very useful.

Portable Pneumatic Shears.—Shears of this description are of great service in connection with breaking up ships, boilers, etc., also in repair work, as it becomes possible to shear off rivets and bolt heads, etc., without damage to the plates, as a portable power shears are as light and efficient as anything of their kind. They can be slung from a crane, air-hoist, or any suitable appliance, and readily brought into position. They consist mainly of an air-cylinder and piston operating on a toggle-joint to work the shear blades, and will conveniently deal with bolts, etc., up to 1⅛ inch diameter.

Mining Drills.—The application of the principle of the pneumatic rotary motor for drilling through fire clay, coal and other ores, is likely to meet with considerable success. Piston air-motors such as have been described, with slight modification as to the feeding arrangement, are now being used for coal mining work, and will drill a 2½-inch hole through 6 feet of coal per minute. They are exceedingly light and easy to handle, and the results so far promise an extended application.

When making comparison of the cost of work between pneumatic tools and hand-labor (and it must be borne in mind that they compete largely with hand-labor), it is necessary to take into consideration three points: (1) That with the same sized shop and the same standing expenses in the form of rent, rates and taxes, and wages bill, a very great deal more work can be turned out in the same time. (2) That although against this there must be set off the cost of producing the compressed air, yet even supposing this equaled the cost of manual labor (which it does not) there would still be a considerable saving for the reason given in item 1. (3) That with hand-labor, especially in riveting, calking and place drilling, work can only proceed at a comparatively slow rate, however many men be employed, and however closely together they work. This frequently becomes a serious matter in ship and bridge building, railway works, etc., and even were the cost double that of hand-labor, other advantages as regards speed, etc., would outweigh it; but, as a matter of

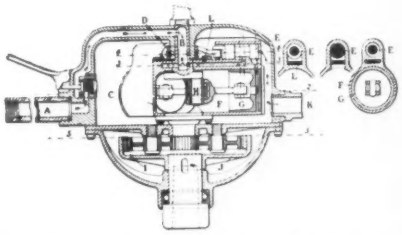


FIG. 22.—"LITTLE GIANT" HIGH SPEED ROTARY DRILL. SECTION THROUGH VALVE.

fact, when properly carried out the saving is very considerable, and it is in the author's opinion only a question of time, and that not far distant, when every engineering shop will find it absolutely necessary, if it wishes to keep in the van of progress, to adopt the pneumatic or some similar system of portable tools.

The author is aware that his paper will lend itself to considerable criticism, because:—(1) He is dealing with a subject which, although a most important one, is yet in comparative infancy; and (2) because there are at present widely different opinions held by engineers as to the advantages of the system; and (3) on account of the very rapid improvements which are being made in the construction and design of the tools, which not only makes it difficult to obtain particulars of the latest types, but renders any data as to their efficiency to become soon unreliable. The makers admit that many of these

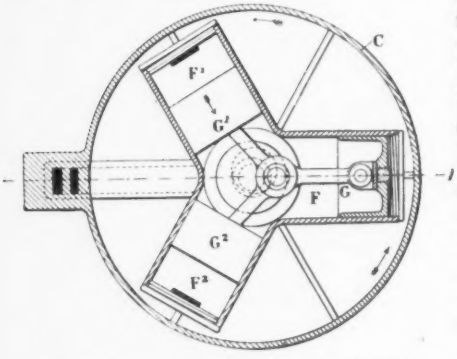


FIG. 23.—"LITTLE GIANT" DRILL. SECTION THROUGH CENTER OF CYLINDERS.

tools are in a state of transition. There is, however, in the author's opinion, a wide future for this class of labor-saving machinery.

The discussion which followed brought out the following points: Tools with hook handles were easier on the operator, working with less vibration than the type with a ring or closed handle.

Mr. Benjamin Martell, chief surveyor of Lloyds' Register, in referring to his experience with work done by pneumatic tools, said he had no hesitation in saying that penumatic tools could produce the soundest work. He had seen the tools in operation, he had seen the ⅞-inch rivets driven by the "Boyer" hammer, and had had the plates slotted through, so that it could be seen how the rivets were laid up and filled the holes. He had assured himself that it could be done. In the next place, the rapidity with which the work could be done, as compared with manual labor, had to be considered. By doing the work rapidly there was an enormous saving in the expense. Then if rapid and constant work could be guaranteed, that was a great advantage to employers, who could insure themselves being able to complete the contracts in the time calculated and contracted for. Another very important matter was the expense. Mr. Badcock, in a letter written to Mr. Cramp of Philadelphia, who was extensively using pneumatic tools, had written: "As I understand that you have finally made a start on the pneumatic riveting, probably some figures I have just had made up as to the results of the work with those tools in our yard for the last three weeks will be interesting. I therefore inclose a statement of rivets driven during the three weeks ending October 12, from which you will see that with a total of over 95,000 rivets the average cost of the machine-driven rivet is only ¼ cent against 3.19 cents, which would have been the cost if those rivets had been driven in the old way by hand. . . . This makes an average saving per minute of 1.09 cent, making the average cost of machine rivets only 47 per cent. of the hand cost, or a saving on each ship of the class we ordinarily build of from 5,000 to 6,000 dollars on one ship. Of course, you cannot expect at the start to make such a saving as this, but I see no reason why in a comparatively short time results equally as good may not be obtained in your yard. It does not take much except ordinary common sense and plenty of compressed air to handle these machines."

In making a comparison between pneumatic tools and electrically driven tools, there were distinct uses for which each machine was quite superior. For instance, if power was required in the shape of a blow, then obviously compressed air was the best; but if it was required to drive a machine above 1 h.-p., and at some distance away from the source of its work, then electricity was better. To make his meaning clear, and to show that there were some fields in which both systems were rivals, he should like to draw attention to some fundamental points in connection

with the two systems. To begin with, the pneumatic drill was self-contained, that was, the drill was direct on the machine, while, except in the case of very small electric motors, it was necessary to use a flexible shaft. Also, an electric motor was very much heavier than a compressed-air drill for the same power; but if a flexible shaft was used, the drill was very much lighter than the pneumatic drill, and consequently it was much easier to set up over the work to be drilled. Then, again, a compressed-air drill might be reversed with impunity, which is not the case with a flexible shaft and electric motor. Another thing about electricity was that a cable could be put where perhaps a pipe line might be in the way. He would take an example or two of the work at Poplar, where sometimes a choice had to be made between the two systems. If in the deck of a boat they had to drill large ventilator-holes, and the small holes for the flange of the ventilator, then they would use electricity, which could be very easily carried from one end of the ship to the other, and the flexible shaft could be easily connected to the boring power for making the large holes, and then to the little drill for making the small ones. In expanding boiler-tubes, compressed air would be used, because it was self-contained and there was no flexible shaft to get in the way of the man, and at the same time it was reversible, which the flexible shaft was not. If small vertical holes were being drilled in the deck of a boat, then the electric motor was used, because the weight of the motor helped to push the drill through; but in drilling small holes for cylinder lagging, or bulk-heads, little holes about ¼ inch, then compressed air would be used, because the man could hold up the small breast-drill where it would be impossible to hold up the electric motor. So it would be seen that every case required careful study of the circumstances, and it was best to have both systems. In conclusion, he expressed his feeling of gratitude to the author for bringing so valuable a paper before the Institution, and he was quite assured that if any member put the system into his works, he would wonder in a few months' time how he had got on without it, and he would more fully appreciate the paper than perhaps he did now.

Mr. J. W. Duntley stated that Messrs. Cramps' shipyard of Philadelphia had to-day over 300 air-tools and were now putting down compressors to furnish 17,000 cubic feet of free air per minute; they were paying 35,000 dollars for the piping of their yards, and had just won a strike over 7,000 men, who went out about two months ago on account of the use of the long-stroke hammer. The Russian navy yards were about to put down a large number of air-tools: and the inspector informed him that the machine-work was so superior to hand-work that it would only be a short time before the European shipowners would ask all shipbuilders to use pneumatic riveting. It required a rivet one-eighth of an inch longer to drive with a pneumatic hammer than to drive it by hand, and the riveting was very much superior, as the hole was entirely filled up. In removing a faulty hand-driven rivet from a ship the head was cut off, and by giving it a blow the rivet flew out. In removing a rivet driven with a pneumatic hammer, after the head was cut off it was necessary to drill the rivet out. Also 97 per cent. of the railroads in America to-day were using pneumatic tools and drills, wood-boring, and painting machinery, and doing every class of work that a railroad had to do by compressed air. Breaking stay-bolts and that class of work was now practically entirely done by air-tools, which also effected great saving in flue cutting.

WORKING RESULTS OF PNEUMATIC DRILLING MACHINES.

No. 1 Machine.

Drilling	½	inch	hole	through	1¼	inch	mild	steel	plate,	3 mins.	15 secs.
"	¾	"	"	"	1¼	"	"	"	"	4 mins.	
"	1	"	"	"	1¼	"	"	"	"	6 mins.	25 secs.
"	1¼	"	"	"	1¼	"	"	"	"	8 mins.	10 secs.

No. 2 Machine.

Drilling	½	inch	hole	through	1¼	inch	mild	steel	plate,	5 mins.	20 secs.
"	¾	"	"	"	1¼	"	"	"	"	7 mins.	
"	1	"	"	"	1¼	"	"	"	"	11 mins.	30 secs.
"	1¼	"	"	"	1¼	"	"	"	"	13 mins.	

TESTS MADE WITH "LITTLE GIANT" PNEUMATIC TOOLS, APRIL, 1900.

Type of Machine.	Work Done.	Time taken.		Average pressure of air used per sq. inch.
		Mins.	Secs.	Lbs.
2,000 lbs. Pneumatic Chain Hoist.	1,980 lbs. weight lifted 6 feet high.	1	0	72
No. 2 Drill . . .	Drilling 1-inch diameter holes through toughened steel armor-plate 4¼ inches thick.	9	15	70
No. 2 Drill, fitted with circular band-saw . . .	Cutting out in one piece a disc of wood 7 inches diameter by 1-inch thick for lamp-hole in railway carriage.	0	30	100
No. 12 Reversible Drill.	Expanding locomotive boiler-tubes, 1⅞ inches outside diameter.	0	30	70
No. 5 Reversible Drill.	Expanding 1-inch diameter steel condenser-tubes	0	30	70
No. 2 Hammer. .	Riveting 1-inch diameter copper stays, knocking down and finishing with snap.	2	30	71
No. 2 Hammer. .	Riveting 1-inch diameter wrought-iron studs cold.	1	0	70
No. 2 Hammer. .	Chipping Bessemer steel-plates ½-inch wide, the chipping taken off being ½-inch thick by 18 inches long, and weighing 11 lbs. 10 ozs. in one piece.	2	56	71

NOTE—The boiler-tube test was made at the Great Western Railway Works at Swindon, and the cutting lamp-holes at the London & North Western Railway Works at Wolverton.

Observations on Compressed Air Illness.

FREDERICK R. WAINWRIGHT, M. D. MCGILL, M.R.C.S. ENG., L.R.C.P. LOND.

The opportunities afforded for the observations of the pathological effects of high atmospheric pressure have been relatively very few and the testimony of every additional observer may be of value in aiding in the elucidation of a rather obscure subject. It is for this reason that I venture to publish these remarks, which embody my experience and the conclusions at which I have arrived as the result of that experience. It is not my purpose to discuss the physiological effects of compressed air on the human economy, for in my opinion observations along this line made during the progress of an engineering work of great magnitude would not afford trustworthy results, there being so many factors apart from the actual air pressure which would tend to render one's conclusions inexact. Neither is it possible within the limits of this paper to give an account of the history of the use of compressed air in engineering operations from the invention of the diving bell in the sixteenth century up to the present time. A very complete account of the subject has already been given by Dr. E. H. Snell in his excellent little book on "Compressed Air Illness," together with his own experience while acting as medical officer to the Blackwall Tunnel.

It seems probable that in the future compressed air will be used to a much greater extent than it has been in the past, and the knowledge as to the best means of reducing to a minimum the suffering inseparable from this class of work will be of value not only to the workmen employed, but also to the employers themselves. At the Baker street and Waterloo Railway tunnel works we had, considering the pressures employed and the length of the shifts, remarkably few cases of illness. The opinions which I hold as to the reason of this comparative immunity I will endeavor to express later.

It is a matter for regret that so much work under compressed air has been done in which no medical records were kept, and this is not only the case with undertakings carried out many years ago, for even in so recent a work as the St. Clair Tunnel, under the St. Clair river in America, there seem to have been no accurate medical records, though I gather from a general description of the tunnel that there was much illness and that several deaths occurred. Among the best records of the last 30 years are those of Dr. Jaminet of the St. Louis Bridge and Dr. A. H. Smith, the medical officer at the construction of the Brooklyn Bridge. But while admitting the value of their observations, I totally disagree with their conclusions as to the pathology of the condition and also as to some of the factors which are instrumental in its production.

For the better understanding of the conditions under which the men employed in the compressed air worked it will be well for me to give a short description of the tunnel. It was only in a certain portion of the tunnel that the use of compressed air was necessary—that part of it which ran through the ballast in the bed of the river Thames. The tunnel was reached by two shafts sunk through a staging erected in the river, the top of the tunnel being a few feet below the bed of the river. Before the shield had reached the ballast the river crossing section of the tube was cut off from the other part by a brick diaphragm into which a lock, with doors closing airtight, was fitted. At each end of the lock was a tap for the purpose of admitting the air from the pressure section when entering or for allowing it to escape into the other portion of the tunnel when leaving the compressed air. It was possible to fill the lock up to 30 pounds per square inch in one and a half minutes and to empty it at the same pressure in one and three-quarter minutes.

A few remarks regarding the astonishing rise in temperature when "locking-in" may be of interest. I have noted the mercury rise, when "locking-in" with a "full tap" at 30 pounds pressure, from 60° F. to 115°. During "locking-out" I have seen it fall from 90° to 46°. Foley assigned a very important place to this cold, misty atmosphere in the production of the illness. While quite admitting that such sudden variations in temperaure are not advantageous I do not consider that they play the smallest part in the etiology of the condition. The air was conducted from the air compressors to a large tank beneath the water, passing through this before being delivered into the tunnel, the idea being to cool it to some extent. I doubt whether this plan was very effec-

tual, for on several occasion I took the temperature of the air as it left the supply pipe and found it to vary between 110° and 120°, according to the speed at which the air compressors were running. As it passed along the tunnel and escaped at the face it cooled to about 85°.

The pressures in the tunnel varied with the state of the tide and the nature of the ballast met with. As a general rule at low water the pressure was from 23 to 25 pounds per square inch, at high water from 28 to 30 pounds, and on several occasions it was as high as 35 pounds per square inch. It is to be remembered that these figures refer to pressures over and above the 15 pounds per square inch normal atmospheric pressure.

VENTILATION.

When it became necessary to use the air pressure the river crossing tunnel had already progressed so that the face or shield end was 123 feet from the lock. Thus, to begin with, there was a fairly spacious chamber for the men to work in. The ventilation during the whole time that the shield was in the ballast was excellent, on account of the very free escape of air through the gravel at the face. I was in the habit of estimating three times daily the amount of air pumped into the tunnel, and found that it gave an average amount per hour of about 6,000 cubic feet for each man. This amount was well distributed, for, on my recommendation, the supply pipe emptied just at the lock, thus causing the air to sweep from one end of the tunnel to the other in order to escape at the face. Before this was done the air at the face had shown 0.06 per cent. carbonic acid gas and at the lock end 0.09 per cent. After the alteration in the pipe the whole tunnel showed the same amount, varying between 0.06 and 0.07, which degree of purity was maintained until Oct. 4. On this latter date, the shield being again in clay, the air could not escape at the face, and we had to depend on artificial ventilation. The percentage of carbonic acid gas rose at once to 0.081, then to 0.1, and could not be brought below 0.075 till Oct. 28, when the compressed air was dispensed with. How this difference in purity affected the amount of illness I will point out further on. The tunnel was lighted by electricity which, by obviating the necessity for the use of candles or gas, materially improved the conditions. The men were divided into three gangs, each gang doing a "shift" of eight hours. The men working in the face, and who were exposed to wet, were provided with clothes which they changed on leaving the tunnel and which were dried before being again used. A well-warmed room was also provided for the use of the men to induce them to rest before going home, but of this they never took advantage. Hot coffee was supplied to them on leaving the tunnel, and was much appreciated by them. I have no doubt that it was of benefit after the cold atmosphere of the lock. Smith states that it appeared to relieve to some extent "the nervous prostration which marked the return to the open air." I was never able to detect the smallest sign of nervous prostration in the men coming off a "shift," so I cannot offer any opinion as to the value of coffee in the condition. Before allowing any man to commence work in the compressed air I subjected him to a physical examination, paying particular attention to the condition of his heart and arterial system. Very stout men and those advanced in years were not accepted, though considerable latitude may be allowed in these conditions. Alcoholism, I consider, should debar a man from this class of work, and I rejected any man who on presenting himself showed signs of recent excess. Of the 120 men passed 88 had previously worked in compressed air, while 32 had no previous experience. The youngest man was 19 years of age and the oldest was 52 years, the average age being just over 30 years.

In all, during a period extending from May 23 to Oct. 28, 1900, 47 cases of illness, due to work in compressed air, came under my treatment. These cases occurred in 40 different men, two having three attacks each and three having two attacks each. In these figures I include only those cases which were of sufficient severity to call for treatment. I do not believe that a single man escaped a slight twinge of pain at some time or other to remind him of the nature of his occupation, but these were very evanescent and they cannot be dignified by the name of illness.

PATHOLOGICAL EFFECTS.

The pathological effects of compressed air are manifested at two distinct times and are due to entirely different conditions. The first class is purely mechani-

cal and is noted when going into, or when actually in, the pressure. The second class comprises those symptoms which are only seen after leaving the compressed air.

The symptoms consequent upon mechanical pressure *per se* consist of pains in the ears, frontal and maxillary sinuses, and in carious teeth. Pain in the ears is common when "locking-in" for the first time, especially if the pressure be rapidly admitted, but is rarely met with afterwards unless there be a condition of "cold in the head," pharyngitis, etc., which interferes with the normal potency of the Eustachian tubes. The pain has all grades of severity, from a mere sense of oppression to the most acute agony. It is, of course, due to the fact that if the Eustachian tubes are blocked the pressure outside the drum is greater than that in the middle ear and the membrane is pushed forcibly inwards. If the Eustachian tube remains closed and the pressure be sufficiently great rapture of the tympanium may ensue. This actually occurred in two cases which came under my notice, in one of which I myself was the patient. The injury had no permanent ill-effects in either case. Apart from actual rupture the relative vacuum in the middle ear brings about a congestive condition of its lining membrane which, according to Dr. Snell, may result in inflammation which may be followed by suppuration. I had no case of this kind brought to my notice. The pains in the frontal and maxillary sinuses do not call for special mention. In my experience they were very infrequent, and I never observed them apart from a catarrhal condition of the nasal mucous membrane. In these cases, during "locking-out," there may be a discharge of blood-stained mucus from the nose. The foregoing conditions are, as before stated, dependent on mechanical causes, and cannot well be considered as part and parcel of compressed air illness. Furthermore, in my experience, they never occurred apart from an abnormal condition of the mucous membrane of the nose or pharynx, therefore I cannot regard them as a necessary accompaniment of exposure to an atmospheric pressure above the normal.

In the second class are those symptoms which are only manifested after leaving the pressure. These symptoms, though perfectly distinct from each other, are, I believe, all due to the same underlying pathological conditions. The most frequent and characteristic manifestation is pain, usually occurring in the joints, less frequently in the muscular structures of a limb. In only one of my cases were the muscles of the trunk affected. The pain may be confined to one joint, or may be present in two or more joints, the latter condition being the more usual one. In my series of cases the knee was the only joint to be affected singly, and this only occurred in four cases out of the forty-seven. The knee joint is more frequently attacked than all the other joints combined, and in 19 of my cases the knees were the seat of pain apart from any other manifestation, and in 16 cases pain in the knees co-existed with other symptoms. Next in order of frequency came the elbow joint, which was affected in 11 cases, then the shoulder with seven cases to its credit. The hip joint was the seat of pain in five cases, the wrist in three cases, and the ankle in one case. Any number of joints may be simultaneously affected. The pain varies from a mild ache to the most severe suffering, and in well-marked cases I know of no condition which produces a greater degree of physical agony. The patient becomes pallid and perspires freely, the pulse is hard and rapid, and unless he is possessed of a considerable amount of self-control the man cries and groans. The pain has been described to me as "a feeling as if the joints were being twisted off" or "as if a dog were gnawing a bone." If untreated the pain may disappear in five or six hours or it may persist with diminished intensity for several days or even weeks. The onset of the pain may be at any time after coming out of the compressed air. In some cases it comes on immediately, in others not for several hours. The longest interval in my own case was five hours, but Dr. Snell gives notes of a case in which 14 hours elapsed between leaving the pressure and the appearance of the pain. As a rule not more than two hours elapsed. I have almost invariably found that the sooner the symptoms appear after leaving the pressure the more severe they are. Swelling is not common in the joints, but is invariably present if the pain is situated in the muscles. I have never found any tenderness present, even vigorous friction relieving, rather than aggravating, the pain. I am aware that on this point my experience is directly contrary to that of most other observers. Epigastric pain and

vomiting may occur and are usually very severe and refractory to ordinary treatment. In well-marked cases the pain is intense and the vomiting is persistent. This condition only occurred in about 10 per cent. of my cases and Dr. Snell only found it in a small percentage. On the other hand, Dr. Jaminet describes it in 78 per cent. of his cases and Dr. Smith in 24 per cent. Formication or itching of the skin followed by redness may occur; only one such case came before my notice.

Cerebral symptoms.—Headache and giddiness are not uncommon as following exit from the compressed air. In four of my cases giddiness was very pronounced, the patients reeling and falling down. Pain in the head is not necessarily present, but may exist along with the giddiness. Vomiting is not uncommon in these cases, being cerebral in character and quite apart from any gastric disturbances. Visual troubles, such as diplopia and flashes of light, may be present. As a usual thing these symptoms are of short duration, and they yield very quickly to appropriate treatment. Dr. Snell gives notes of nine cases of vertigo occurring after exit from compressed air. The onset in all the cases was sudden, and in six of them some amount of deafness was present, tinnitus occurring in four cases. In some of these cases the vertigo lasted for many months. No case of auditory vertigo due to working in compressed air came under my notice, so I am unable to speak of it from personal experience.

Paralysis.—Paralysis only occurred in one of my cases, the condition being one of paraplegia with involvement of the bladder and rectum. Dr. Snell only had two cases at the Blackwall Tunnel, while in New York Dr. Smith observed it in 15 per cent. of his cases, and at St. Louis it was present in 61 per cent. Dr. Smith says that the paralysis most often affects the lower half of the body but may include the trunk or arms. According to him pain may or may not be present in the limbs even when tactile sensation is lost. In my case the only pain felt was on each side of the spine in the lower lumbar region.

Death.—Death is not a very uncommon sequence of work in compressed air, and it may occur suddenly on leaving the pressure or after previous paralysis or other symptoms. Out of 76 cases of illness at St. Louis Bridge there were 12 deaths. Dr. Smith had three deaths in 110 cases, and four deaths occurred in sinking the caisson for the Londonderry new bridge, and this with a pressure of only 28 pounds. As far as I can discover, the Forth Bridge and Blackwall Tunnel were the first works using high pressures which were put through without a fatality. At the Baker street and Waterloo Railway Tunnel works we had no fatal case.

DIAGNOSIS.

When we consider the devious workings of that peculiar statute known as the Employers' Liability Act, it becomes a matter of some importance that these cases should be carefully diagnosed and differentiated from other conditions having somewhat similar symptoms. It must also be remembered that the pains may possibly be assumed, the man hoping thereby to be a financial gainer. I agree with Dr. Snell that the most important points in the diagnosis are the time and manner of the onset. Physical signs being rarely present in any form, there is little else to go upon. Personally I would not admit a case to be due to compressed air where twelve hours had elapsed from the time of leaving the pressure till the onset of the symptoms. Rheumatism, osteomyelitis, and arthritis deformans are not likely to be mistaken for the joint pains of compressed air illness. The absence of any rise of temperature in the latter, together with its sudden onset and freedom from physical signs, will serve to distinguish it. I here insert a note on one of my cases which was interesting, not only from the point of view of diagnosis, but also because I am unable to find a similar case recorded in any of the writings on compressed air illness which I have been able to consult.

CASE I.—The patient, a strong, healthy man, aged 50 years, rather inclined to be stout, had worked in compressed air before coming to the Baker street and Waterloo railway tunnel works, and had been employed at these works for some time. On August 29, 1900, he came out of the tunnel at 6 a. m., after doing an eight-hour shift. At about 6.30, when he reached home, he felt a pain "in the front of his chest." He at once got very short of breath and felt very distressed though the pain was very slight. He had a feeling of impending death. He managed to return to the stage, stopping every few yards to get his breath, and

he reached there at 10.15 p. m., and I at once saw him. He was then in great distress and was unable to speak more than a few words at a time. His face was very dusky. I have never seen more severe dyspnœa. The pulse was 120 and very feeble, and the respirations were 45. I at once auscultated his chest and found a most peculiar state of affairs. Posteriorly there was nothing abnormal and the supraclavicular regions were negative. But all over the front of the chest a most unusual sound was heard, audible throughout the whole respiratory cycle. I have never heard anything like it before, consequently I am unable to give any comparative description of it. It was very harsh and creaking, sometimes tearing, in character, and most marked between the third and seventh costal cartilages on the right side. I then percussed the chest with absolutely negative results, and on applying my stethoscope immediately afterwards I found that all the auscultatory phenomena had disappeared. There was no cardiac displacement and there were no murmurs, but the sounds were very distinct and feeble. As the man was evidently in a serious condition I at once put him into the medical lock and re-compressed him up to 18 pounds, at which point all dyspnœa had gone and he felt perfectly well. This pressure was allowed to "leak out" in 70 minutes and the patient came out of the lock feeling quite well. There was no return of the symptoms. No physical signs could be discovered after coming out.

Now, in this case there might have been considerable difficulty in the matter of diagnosis. The mode of onset certainly pointed to compressed air as the causative factor, but it was hardly possible to be certain until the immediate cure of the condition by re-compression removed all doubt as to the nature of the trouble.

ETIOLOGY.

The one essential for the production of this illness is, of course, a sojourn in an atmospheric pressure above normal. This, however, does not in itself cause any of the symptoms given above, but only brings about the conditions necessary for their development after the subject returns into a lower pressure. It must be thoroughly understood that there are no manifestations of this illness so long as one remains in the compressed atmosphere; it is my belief that a man might live in a pressure of three atmospheres for an indefinite time without necessarily experiencing any ill effects. In addition to the essential cause there are other factors which are very important, the first two in order of importance being the length of stay in the pressure and the amount of carbonic acid gas present in the condensed atmosphere. The influence which the latter has upon the former of these two factors is so great that it is hard to separate them in considering the share which each one has in the production of the illness. Dr. Snell has enunciated a law that the amount of illness varies inversely with the amount of fresh air supplied. With this I thoroughly agree, and when considering the length of time spent in the pressure the carbolic acid gas factor must be thought of, and, within certain limits, it may be laid down that the time which may be spent in the pressure without resulting bad effects depends very largely on the percentage of carbonic acid gas present.

Leaving aside the question of ventilation for the moment and assuming the percentage of carbolic acid gas to be a fixed quantitv. then the length of stay in the pressure is, in my opinion, the most important accessory in the etiology of the disease—far more important than the time employed in leaving that pressure. At the Baker street and Waterloo railway tunnel there was no case of illness occurring in a man who had not been at least three consecutive hours in the pressure. In addition to the regular eight-hour workers there were many men, such as fitters, plate-layers, gaugers, etc., who spent variable periods of time in the condensed atmosphere, so that I had an excellent opportunity of proving this point.

Regarding the relative importance of the length of stay in the pressure as a factor in the production of the disease opinions have differed. Dr. Jaminet recommended short shifts at the St. Louis Bridge, but nevertheless he considered the time spent in "locking-out" as of primary importance. According to Dr. Snell, Mr. Eads, the chief engineer of the bridge, was the first to call attention to the fact that the length of stay was more concerned in the production of the illness than the rapidity of "locking-out." Dr.

Smith attached great importance to the length of stay in the pressure and he formulated the law that the danger is as the degree of pressure to which the person has been exposed multiplied by the duration of the exposure. At the Brooklyn Bridge the pressures rose gradually, with the depth of the caisson, from 18 pounds to 36 pounds per square inch, the length of the shifts being four hours at first, gradually reduced to two hours as the pressure increased. Even with these short shifts Dr. Smith reports 110 cases of compressed-air illness as occurring in four months. At the Baker street and Waterloo railway tunnel, where eight-hour shifts were worked, there were only 47 cases in five months. At first sight these figures would appear to show that the length of stay does not play a role of any importance in the production of the illness. But it is precisely here that the carbonic acid gas factor comes in and proves itself to be of such importance. At the Brooklyn Bridge caisson the air contained 0.33 per cent. of carbonic acid gas, while at the Baker street and Waterloo railway tunnel, as has already been stated, the percentage up to the last three weeks was kept at from 0.06 to 0.07. Dr. Smith seems not to have considered ventilation as of any importance, and he makes the remark that "this amount (0.33) of vitiation was found not to affect the men unfavorably." In my opinion it was just that vitiation which was responsible for his large number of cases. No doubt it also had much to do with the "nervous prostration" which he observed in men coming out of the pressure. It is true that Dr. Smith had a larger number of men than were employed at the Baker street and Waterloo railway tunnel, but had we worked in four-hour and two-hour "shifts" instead of in "shifts" of eight hours the number of our cases would, in my opinion, have been insignificant.

Dr. Snell claims to have been the first to point out the relationship between the amount of illness and the fresh air supplied to the compressed air space, and he gives some very interesting tables from his experience at Blackwall in support of his views. My own observations on this point were necessarily limited as the air supply was large and constant up to nearly the end, but the figures I am able to give are, I think, sufficiently striking. From May 23 to Oct. 4, with an average of 6,000 cubic feet to each man per hour, there were 34 cases, say, eight cases per month. Following this with an average of 1,700 cubic feet to each man per hour there were 13 cases in a period of 12 days. I found also that the cases occurring during the latter period came on sooner after leaving the pressure and were of greater severity than those occurring during the time of good ventilation.

I do not assign a very important position to rapid "locking-out" as a cause of the illness, though I am firmly of the opinion that could this process be sufficiently prolonged it would probably altogether prevent subsequent symptoms. But in order to achieve this result three-quarters of an hour at least would be required to be spent in coming out of a pressure of 30 pounds to the square inch, and this, from an economic point of view, would be impracticable. Some observers have laid down very precise mathematical rules as to the length of time to be spent in reducing given pressures, though it is difficult to see on what these rules are based. Dr. Smith says that five minutes should be allowed for each additional atmosphere, while Dr. Jaminet gives one minute for each additional six pounds of pressure. At the Baker street and Waterloo railway tunnel it was possible to "lock-out" of 30 pounds pressure in one and three-quarter minutes during the first three months. After that the exit tap was altered so that to leave the same pressure required at least six and a half minutes. This alteration did not in the slightest degree affect either the number or the severity of the cases.

There are some minor predisposing causes which have been assigned different degrees of importance by various authorities. Among these newness to the work, age, alcoholism, and obesity are the chief. With regard to an old hand being less liable to compressed-air illness than a newcomer, opinions differ. Dr. Smith strongly adheres to this view, though admitting that some very severe cases occurred among old hands. Dr. Snell does not admit the increased liability of a new hand to the disease, but says that it is very difficult either to prove or to disprove it. Personally it is a point upon which I am uncertain, though my figures would tend to show that a man is more susceptible when he first begins this class

of work than after having been engaged in it for a greater or less period. Of 88 men who had previously worked in compressed air 25 were affected, or 28.4 per cent., while of 32 men who had had no previous experience of such work 15 were affected, or 46.8 per cent. Of the 40 men who were affected, in 16 the illness occurred after the first "shift"—that is to say, in 40 per cent.

Age has been considered to be an important factor, the amount of illness varying in proportion to the age. The only statistics which I can find are those given by Dr. Snell from his own experience, and covering, as they do, a large number of men of all ages they have an especial value. He concludes that below the age of 20 years men are singularly exempt from this illness; between the ages of 25 years and 45 years the liability to illness does not vary to any great extent, but is about twice as great as between the ages of 20 and 25 years, and that after the age of 45 years the liability increases very considerably. My own conclusions, though based on a much smaller number of men, agree with those of Dr. Snell, and I am of the opinion that young men stand compressed air better than do those of more advanced years. But it is only in the very young ones that a marked immunity is observed, the amount of illness from 25 to 40 years not varying much according to the age.

Fulness of habit has been noted by many observers as specially predisposing to the untoward effects of compressed air. Dr. Smith made a strong point of this in his essay on caisson disease, and he gives figures in support of his views which show that of 86 cases of illness the spare men were responsible for 28, the medium for 22, and the heavy for 36. He adds: "Considering that among laborers below the age of 45 (and none were above that age) the class described as heavy are very much in the minority, these figures are sufficiently striking." As I excluded all men who were conspicuously stout, I have not been able to form any opinion from observation on this point. But I am quite sure that the cases occurring in moderately large men were neither more numerous nor more severe than those in men of light build.

Alcoholism has been said to strongly predispose to compressed air illness, a man who has been drinking heavily being frequently a sufferer, and certainly some of my most severe cases occurred after a too free indulgence. But this is a point upon which it is hard to come to a satisfactory conclusion, for the reason that, with two exceptions, all the men used alcohol, the majority freely, so that no comparative statistics could be obtained. But I am inclined to the view that alcohol is a predisposing factor of considerable importance.

Muscular exertion following upon exit is insisted on by Dr. Jaminet as being of importance in bringing about the symptoms, and he noted a diminution in his cases when the men were drawn up instead of reaching the top of the caisson by climbing the ladders. Dr. Smith also supports this view, but admits that he has no figures to offer. At the Baker street and Waterloo railway tunnel the men were drawn up in a cage and were forbidden to mount the ladders, but always hurried away as soon as they reached the top. Two of the men used bicycles, riding home a distance of six miles immediately after coming out of the compressed air, neither of them having an attack throughout the whole five months. I have never been able to see any reason for supposing that muscular exertion after exit increases the liability to the illness, though I do not deny the possibility of its being so.

Pathological Theories.

Very many theories have been put forward in an endeavor to explain the manner in which compressed air causes the symptoms for which it is responsible. But possibly even more surprising than their number is the fact that so many of these elaborate theories do not in any way harmonize with the observed symptoms and conditions. In many cases it appears as though, so long as the theory happened to be vague and abstruse, its sponsor was perfectly indifferent as to whether or not it could be reconciled to the facts. The symptoms have been variously ascribed to exhaustion, hemorrhage, rheumatism, congestion of various parts, carbonic acid gas poisoning, and supersaturation of the blood by the compressed atmosphere. It would be quite impossible within the limits of this paper to give, with any sort of completeness, the arguments put forward by those who happen to pin their faith to one or other theory. All that can be done is to examine them in a general way and to attempt to point out where,

in my opinion, they appear to fall short.

The exhaustion theory is based on the hypothesis that an increased metabolism follows a stay in compressed air owing to the greater amount of oxygen present. This is purely hypothesis, for, as Dr. Snell points out, no experiments have as yet proved that any such increased activity of the vital processes do occur. On the contrary, many observers have arrived at the conclusion that there are no grounds for such a belief. Personally, though my observations were clinical and not experimental, I have not been able to find any reason for holding that work in compressed air is associated with increased metabolism. Appetite has been said by many to be increased and Dr. Smith says in regard to this that it "seems to point to an increased waste of tissue to be supplied by a greater consumption of food," though he would not accept the explanation as conclusive, believing that this could not occur without increased temperature. I do not presume to doubt those who say that appetite is generally increased, but in my own experience I have not found such to be the case. I carefully questioned some thirty of the more intelligent of the men regarding their appetites when working in compressed air. Only two said that they ate more, the majority that they noticed no alteration, while a few stated that they did not use as much food. Neither is there any rise in temperature. But let us admit, for the sake of argument, this this increased tissue metamorphosis does occur, can we account for the symptoms in this way? Dr. Jaminet held an affirmative opinion, and in fact his treatment consisted together of stimulants and nourishment, but by what process of reasoning he arrived at this conclusion it is beyond my power to conjecture. My own opinion so thoroughly agrees with that of Dr. Snell that I cannot do better than quote his own words. "But if severe and often excruciating pain in the limbs, and elsewhere, paralysis of the legs, bladder, and rectum, and sudden death, are each and all to be ascribed to 'exhaustion,' this term must surely be employed in some more special and technical sense than is usual." Furthermore, this theory offers no explanation of the fact that the illness depends largely on the amount of carbonic acid gas present—i. e., the less oxygen the more illness. Neither does it account for the curative action of recompression in these cases nor for the complete absence of symptoms so long as one remains in the compressed air.

The theory that carbonic gas produces the illness by direct poisoning requires no more refutation than the statement that the symptoms of poisoning by this gas bear no resemblance to those met with in compressed-air illness.

Congestion of the brain, spinal cord, and other organs is considered by Dr. Smith in his essay on caisson disease, by Dr. Moxon in the Croonian Lectures in 1881, and by many other observers to be the cause of this illness. Dr. Smith says that "it is probable that the pathology of this disease is not entirely uniform in all cases," but does not doubt that congestion is the chief element in it. But in his further elaboration of this theory he assigns congestion the chief and only place, although not bringing forward a single fact which goes to prove his contention. He begins by making the statement that the centres will be congested at the expense of the periphery in a compressed atmosphere, and having laid down this law in no uncertain manner deduces a second law "that firm and compact structures will be congested at the expense of those more yielding," and on top of this a third law "that structures within closed bony cavities are congested at the expense of all others." Now it is the easiest thing in the world to deduce a law from a statement, the difficult matter being to be quite certain that the statement is correct. Does the blood, as Dr. Smith says it does, pass from a place where the pressure is greater to one where it is less, and if so, where does it go to find a place which is not already filled with matter, either fluid or solid, or how can it increase the tension in these central parts when, as Dr. Snell well puts it, "blood-pressure is everywhere raised and every one part of the body presses with greater force on every other part?" The only compressible parts are the free gases in the alimentary canal and I can corroborate Dr. Snell's opinion that this potential space is principally occupied by the abdominal wall being pressed in, as, from my own observations, the latter is the case when one goes into a compressed atmosphere. If the blood under pressure leaves, say, the periphery of a limb, how does it do so except as a result of compression of that

limb? Dr. Smith says that solid structures resist compression. How, then, are the fluids contained in the solid structures going to be driven out of them? It would seem as reasonable to say that one might by compressing a glass bottle squeeze water out of it without altering its shape. In order for the pressure to act on the blood it must necessarily do so by compressing surrounding structures. But in compressed air there is not the least evidence of this taking place. The limbs are not altered in the least degree either in size or in shape. Dr. Smith says that superficial veins are obliterated and that the skin is anaemic, and he even makes the statement that the hands are shrunken and shrivelled owing to the blood being squeezed out of them. Now I have repeatedly examined the men while in the pressure in order to ascertain to what extent I could corroborate these observations of Dr. Smith's. In my experience I can emphatically say that these phenomena did not occur. The skin does not become anaemic, the veins are not effaced, nor are the hands altered in appearance in the slightest degree. But on other grounds it is difficult to admit the engorgement of the internal structures assumed to occur by the exponents of this theory. Is it reasonable to suppose that a man could work, and work hard, for eight consecutive hours with his brain, spinal cord, liver, &c., in such a congested state, and could do his work without the slightest feeling of discomfort and keep it up, on and off, for years without discoverable ill-effects? To my mind it is most unreasonable. Again, how does this theory agree with the actual symptoms of the illness? Dr. Smith holds that the vessels both in the congested and anaemic parts will suffer from a loss of tone which will bring about a lowering of tension in the vascular system. He also appears to believe that while in some cases the pains are of local origin in most cases they are spinal I believe all the joint and muscular pains to be local and not spinal in origin. And in any case will the fact that the vessels are suffering from loss of tone be sufficient to give rise to a pain of such intensity? Can the case of cardiac dyspnœa, to which I have referred; be put down to congestion, spinal or otherwise? Although Dr. Smith did not use recompression as a therapeutic measure he was impressed with the fact that when a man returned into the pressure the symptoms vanished. He says that he would expect recompression to be of special value in "paralysis not dependent on extravasation of blood." But if paralysis in common with the other symptoms were dependent on congestion, how would recompression be of service? It would simply bring about congestion of the cord once more. Dr. Smith does not attempt to explain why he thinks recompression would act beneficially, and if one were held to the congestion theory it could not be satisfactorily explained.

In the New York Medical Record, 1890, Dr. Corning attributes the symptoms to anaemia of the cord. But it is only in exceptional cases that there are any symptoms which can properly be referred to the cord, and it is perfectly justifiable to suppose that the same cause is at the bottom of all the symptoms, depending altogether for its effect on the part of the body upon which it acts. Finally, neither of these theories explains why carbonic acid gas should be a factor in the production of the illness only second in importance to the pressure itself.

Supersaturation of the Blood—Now we come to the theory which has for its foundation the law of Dalton, which enunciates that fluids absorb gases in direct proportion to the pressure. Water dissolves at 10° C. and under one atmosphere pressure oxygen 0.028 part, nitrogen 0.014 part, carbonic acid gas 0.90 part. It is held that during a sojourn in compressed air the blood becomes charged with the atmospheric gases proportionately to the pressure and that after exit, the pressure being removed, the blood is no longer able to hold the air in solution and it may become free in the vessels and surrounding tissues and thus give rise to the various symptoms met with. We have in this argument an adequate explanation of the symptoms not only of joint pains but of paralysis and other manifestations. I am of the opinion that the case of cardiac dyspnœa which I have recounted can be explained very reasonably as being due to extravasation of air into some situation where it caused pressure on, and consequent embarrassment of, the heart, though what that exact situation was I confess that I am not able to say. Now regarding the absorption by the blood of gases under pressure it has been shown by Bert that such absorption does take

place although not exactly according to the rule laid down in the law of Dalton. Hoppe found that in animals killed by a rarefied atmosphere there were bubbles of free air in the blood. He concludes that the same effect takes place in passing from a condensed to a normal atmosphere. Bucquoy considered that in a compressed atmosphere the amount of gases absorbed by the blood increased in accordance with physical laws and that on decompression gas must escape and may cause in some cases joint and muscular pains and hemorrhages. Dr. Snell as a result of his observations strongly supports this theory of supersaturation of the blood. Now what arguments are there against the tenability of this theory? I have carefully observed every case of compressed air illness which came under my treatment and have considered the conditions which appear to bring about an increase or a decrease in the number of cases, and I have been unable to find any fact which cannot be reasonably explained if we accept supersaturation of the blood as the underlying cause of the symptoms. Dr. Smith, it is true, objects to this theory on the very insufficient grounds that frequently the symptoms do not appear until several hours after leaving the pressure, whereas, in his opinion, if the symptoms were produced by free bubbles of air in the blood-vessels this condition should be at its maximum at once after leaving the pressure and should give rise to the symptoms immediately. His second objection is that the fact of the "comparative immunity from danger which results from repeated exposures to compressed air" could not be explained if the action were due to purely physical causes. He says: "The obstruction of the vessels described by Bert is a condition of which the system could never become tolerant by frequency of repetition." The first objection may be answered by pointing out that the disengagement of the air from the blood is not an instantaneous process, and that very many of the fine bubbles may have to collect before even a capillary vessel can be blocked, and, as Dr. Snell further points out, a still greater collection must take place before stretching and rupture of the capillaries can ensue. Regarding Dr. Smith's second objection it may be said that the comparative immunity acquired as a result of repeated exposures to compressed air is as yet not proven, though personally I am inclined to the opinion that some degree of immunity may result. But even if this be admited I can see no reason why the vascular system should not adapt itself to this condition equally as well as to the condition of congestion described by Dr. Smith. Probably in many of the cases the vessels do not rupture, but the air passes through them into the surrounding tissues. Why should not the vessels acquire a resistance to this or to rupture as well as to congestion? This theory is capable of explaining why the length of time spent in a condensed atmosphere should be of such moment, for saturation of the blood will only take place more or less gradually. We can also see why higher pressures are more dangerous than low ones if we admit the operation of Dalton's law in these cases. It also explains why the symptoms are never observed so long as one remains in the pressure, but only after exit. Furthermore, I am satisfied in my own mind that this theory affords a reasonable and scientific explanation as to why an increase in the carbonic acid gas should bring about an increase in the amount of illness and also why, with an atmosphere containing 0.06 per cent. carbonic acid gas at the Baker street and Waterloo railway tunnel, we had no cases occurring under a three hours' sojourn in the pressure. When we consider the relative solubility of oxygen, nitrogen, and carbonic acid gas, it is within the bounds of probability that the latter is the one dissolved in greatest amount in the blood, though present in such a small quantity in comparison with the other component gases of the atmosphere. The application of the law of Dalton explains why pressure, length of stay in that pressure, and amount of carbonic acid gas present should be so intimately connected one with another that it is impossible to consider one without the others. It is true that Bert in analyzing the bubbles of air obtained in his experiments on animals found them to consist chiefly of nitrogen. But as Demarquay, quoted by Dr. Snell, has shown, free gases existing in the tissues of the body are absorbed at different rates, and while carbonic acid gas is absorbed in 45 minutes nitrogen may be discovered after several weeks. Is it not possible that the length of time intervening between death and necropsy in Bert's experiments may have been sufficient for the disappearance

of the carbonic acid gas? This theory also enables us to comprehend why rapid recompression followed by a long "locking-out" are in a large majority of cases curative in all forms of the illness, the air being reabsorbed and the gradual "locking-out" enabling it to escape through the lungs. It also accounts for the fact that the sooner recompression is practised after the onset of the symptoms the more satisfactory are its results.

Morbid Anatomy.

There having been no fatal cases at the Baker street and Waterloo railway tunnel works I have had no opportunity of seeing for myself the post-mortem conditions present. There have been a fair number of necropsies following death resulting from compressed air, but many of them seem to have been incompletely performed. Congestion of various organs has usually been present and in some cases there has been effusion beneath the arachnoid and blood-clots under the dura mater of the cord. Dr. Smith details one of his cases in which Dr. Janeway of New York performed the necropsy. Death had taken place suddenly within two hours of exit. Nothing abnormal was found except congestion of the lungs. It is not stated whether the cavities of the heart were examined for free air bubbles. The spinal canal was not opened. So far the post-mortem examinations made in this condition are not absolutely reliable, for they seem to have been conducted, as far as can be made out, without the precautions necessary for the discovery of free air in the tissues and vessels. The experiments of Bert on animals seem to have been followed by much closer post-mortem investigations.

Remote Effects of Work in Compressed Air.

Does the human organism suffer any ill-effects which may be described as chronic as a result of being subjected to the action of compressed air? I can only say that I have never been able to discover anything which would lead me to answer this question in the affirmative. Many of the men who came before me had worked on and off in compressed air for periods of five, six, and seven years, yet I was unable to find any pathological condition in their organs or arterial systems except in one case—viz., that of a man, 42 years of age, who had worked for varying periods during the last seven years in compressed air and who showed marked arterio-sclerosis apart from any cardiac or renal condition which could be discovered. This sclerosis may have been caused by his occupation, but it is impossible to say definitely that it was.

Regarding the paleness of the face and the general unhealthy appearance of compressed-air workers insisted on by Dr. Smith, I may say that I was not able to detect a greater degree of pallor in these men than was present in men working in other parts of the tunnel, where compressed air was not used, and which is found in most men working underground. Dr. Snell says in this connection that at the Blackwell Tunnel as ventilation improved the pallor became less marked, so that eventually he could not pick out an air-pressure man by his complexion, though previously he had been able to do so.

Treatment.

In the great majority of cases only one treatment is necessary, and that is recompression. For this purpose we had a medical air lock erected on the stage consisting of a boiler placed horizontally. At one end was a door which was air-tight when closed, and the interior was fitted with bunks, lighted by electricity and heated by steam. A small window and speaking-tubes completed the arrangement. It was connected with the air-compressors and was fitted with a pressure gauge and the necessary taps. The sooner recompression is practised after the symptoms appear the better as a rule are the results. If a long period has elapsed, even though the pain may be benefited, there is always in joint cases marked stiffness remaining, the condition then being not an acute one but simply the result of the bruising and stretching undergone by the tissues.

The amount of pressure needed for relief depends more on the severity of the case than on the original pressure which produced the symptoms. Persons attacked after coming out of 30 pounds per square inch pressure may feel perfectly relieved when the pressure in the medical lock amounts to 18 pounds, others may require to be recompressed up to 25 pounds, although the pressure they came out of was only 23 or 24 pounds per square inch.

Decompression must be slow, and I think that it is of advantage not to re-

duce the pressure faster than at the rate of one pound in three minutes. In my experience recompression never fails to stop the pain, but there are exceptional cases where it returns shortly after exit. In some of these a second re-compression is effectual, in others it is quite useless, and I have given an example of each class in the appended illustrative cases. If the pain returns it invariably does so in the original situation, and the fact that pain should ever return after recompression is probably owing to the creation by the first attack of a *locus minoris resistentiae* which renders the passage of air into the tissues easier than escape by way of the respiratory system. In the cases in which the pain returned I had recourse to morphine, given hypodermically. It must be used in fairly large doses, a quarter of a grain not being sufficient to control the pain in any of the three cases in which I used it.

Ergot is highly spoken of by Dr. Smith, who considered it superior to morphine in relieving the pain. I never found it to be of any benefit except in one variety of case—that in which giddiness and headache are the symptoms. I have used it in doses of from one to two drachms of the fluid extract in cases of this kind and always with the greatest benefit.

In the acute cases it is my experience that liniments are practically useless and the same is true of bandaging.

In the cases of stiffness following the acute symptoms I have used the liniment containing aconite and belladonna recommended by Dr. Snell with the greatest benefit.

Illustrative Cases.

Case 2.—The patient was a strong and healthy man, aged 26 years, who had been working in the Baker street and Waterloo railway tunnel works for six days. He had finished an eight-hour "shift" at 6 A. M. on May 29, and three hours later he had very severe pain in his left hip and thigh. He returned to the works at 8:15 P. M. when I saw him. The pain was then very severe, the left thigh being much swollen, and he could only walk with great difficulty. He was put into the medical lock and the pressure was raised to 18 pounds, at which point the pain had practically gone. The pressure was reduced to normal in 45 minutes and he came out feeling quite well but with much stiffness in the limb. There was still considerable swelling, so the thigh was firmly bandaged and he was given a liniment. When seen on the night of May 30 he stated that he felt quite well and that there was no return of the pain.

Case 3.—The patient in this case was a man, aged 40 years, who had had previous experience in compressed air. He was a strong, healthy man. He came out of the pressure at 6 A. M. on June 14, after the regular eight-hour "shift," the pressure then being 28 pounds. At about 8:30 A. M. he was seized with pains in his left knee and in his right shoulder and elbow. He returned to the stage at 2:30 P. M. and I re-compressed him up to 25 pounds, the "locking-out" occupying 50 minutes. The pains before going into the lock were most intense, but on coming out the shoulder and elbow were perfectly well, the knee being slightly stiff. There was no return and he went on his "shift" at 10 P. M.

Case 4.—The patient, a man aged 23 years, had worked in compressed air at Glasgow and had been at the Baker street and Waterloo railway tunnel works for over a month. He had never been affected before. He came off his "shift" at 6 A. M. and immediately on leaving the lock he was seized with most acute pain in his left arm between the shoulder and elbow. He went back into the pressure and obtained instant relief, but on coming out again the pain returned as severely as before. I was sent for at 9:15 A. M. when I found him in great pain. The left upper arm was much swollen and on palpation it gave a crepitant sensation to the examining fingers. He was put in the medical lock and recompressed up to 22 pounds, coming out in 50 minutes. The pain returned but not so severely as at first. I then rubbed his arm with a liniment containing aconite and belladonna and applied a moderately tight bandage without the slightest relief. He was therefore again recompressed up to 12 pounds, at which point the pain had gone. The "locking-out" took 30 minutes. There was no return of the pain after this second recompression. The crepitant sensation imparted to the fingers in examining the arm in this case would lead one to suppose that it may possibly have been due to free air in the tissues. Dr. Snell had a similar case occurring in the thigh.

Case 5.—The patient was a healthy man of small build, aged 26 years, who had had

no previous experience in compressed air. He "came off" at 6 A. M. on Oct. 12, after doing his first "shift," and within ten minutes he experienced most intense pain in both knees. He returned at once to the stage and I saw him a few minutes later, and he was then crying and groaning and apparently suffering very greatly. There was no swelling of the joints themselves, but there was a considerable amount of swelling in the muscles of the thighs. He was put into the medical lock and was re-compressed up to 22 pounds, at which pressure the pain completely went. The pressure was reduced to normal in one and a half hours, and the pain at once returned. He was then given 1½ drachms of the fluid extract of ergot and was re-compressed to 22 pounds, two hours being occupied in "locking-out." The pain immediately returned and was so intense that I injected a quarter of a grain of sulphate of morphia hypodermically and had to repeat it in half an hour. This controlled the pain and the patient slept till 7 P. M., going home soon afterwards free from pain but hardly able to walk on account of the stiffness of his knee-joints.

CASE 6.—In this case a strong, healthy, spare man, aged 43 years, who had had no previous experience in compressed air, came out of the pressure at 6 p. m. on Oct. 10 after being in for four hours, and about an hour later he was seized with most severe pain in the abdomen, the knees, the shoulder, and the elbows. The abdominal pains were most excruciating, and were accompanied by severe and intractable vomiting. He had two physicians at his own home, who, on failing to relieve him, advised him to come back to the works. He was brought back in a cab about 4:30 a. m. on Oct. 11, and I saw him about fifteen minutes later. He was in great agony, groaning and writhing with pain, and had to be lifted into the medical lock. During recompression the abdominal pain increased, and was so intense that he rolled on the floor of the lock; but when the gauge showed twenty-four pounds pressure the pain almost completely left him. The pressure was reduced to normal in 80 minutes, and when he came out of the lock he was quite free from abdominal pains, and the only joint which was still somewhat painful was the left shoulder. In a short time he was able to proceed home. When seen on Oct. 12 the patient said that he felt quite well except for stiffness in the left shoulder. He was advised not to resume work in the air pressure.

CASE 7.—This patient came out of the pressure at 7 A. M. on August 20, having been in just over three hours, the pressure being about 28 pounds. Almost at once he was seized with the most intense pain in "the small of the back on each side of the spine." It rendered him helpless and made him feel sick. I saw him at 7:15 P. M. and he was re-compressed, the pain having vanished by the time a pressure of 15 pounds was reached. Decompression occupied 65 minutes and he was perfectly well on leaving the lock. When seen on the morning of the next day he stated that he felt perfectly well. There was no return of the pain.

CASE 8.—The patient was a strong healthy man, aged 23 years. He had had previous experience in compressed air and had worked at the Baker street and Waterloo railway tunnel works from the commencement. He came out of the pressure at 6 A. M. on Oct. 16 after working for eight hours and an hour later he felt very giddy and began to vomit very violently. There was no pain in the head or elsewhere. He was quite unable to stand. This condition continued for two days and on the third day he began to improve. On Oct. 22 he returned to the works and I saw him for the first time. He was still somewhat giddy, so I gave him one and a half drachms of the fluid extract of ergot and in an hour he said that his head was quite clear. At no time was there any loss of power anywhere, the helplessness being due altogether to the giddiness. The vomiting was severe and intractable.

CASE 9.—The patient, who was a healthy spare man, aged 45 years, had been working in compressed air on and off for the last six years. He had never been affected by it in any way. He had been working at these works since the commencement of operations without having had any trouble. He came out of the pressure at 10 P. M. on Oct. 13, and 15 minutes later he had very severe pain in the lower lumbar region on the right side of the spine and pain of a less marked character on the left side. He also had abdominal pains of moderate intensity. He returned at once to the stage, his lower limbs by this time being completely useless and sensation being much impaired as high up as the iliac crests. I was not sent for,

some of his fellow-workmen taking it upon themselves to recompress him, and at a pressure of 18 pounds all trouble had disappeared and he could use his lower limbs as well as ever. But they reduced the pressure to normal in less than ten minutes and, as was to be expected, the pains in his back and the paresis of the lower limbs returned just as he reached home. On Oct. 14 the lumbar pain had disappeared, but power in his legs was still absent and he had also lost power over his bladder and rectum, a catheter and enemas being necessary. He was brought to the stage on Oct. 15 and I saw him when I obtained the information which I have given above. He was then quite unable to move his right leg and could only just move the left leg. Sensation was imparted, but not completely gone, as high as the iliac crests in front and behind. I had little hope of re-compression or of ergot being of use, the interval having been so long, but I thought it well to try them. He was given one drachm of ergot and was re-compressed up to 25 pounds, the pressure being reduced to normal in an hour and three-quarters. There was no improvement at the time, but an hour later he was able to lift both legs and he said that he did not feel so helpless. Having given him instructions regarding himself he was taken home shortly afterwards. He improved daily and within a week was able to move about on his legs, but the use of a catheter was still necessary. I last saw him on Nov. 9. He could then walk fairly well and sensation was much improved, but it was not yet normal and a catheter was still necessary. In this case I believe recovery will be complete, though it may be several months before the man is able to engage in his ordinary work. As a rule, in these cases the bladder is the last to recover, and the use of a catheter may be necessary for a considerable time after the limbs have completely recovered.

The pathology of these cases of paraplegia in which there is recovery can be reasonably explained by the pressure of air bubbles either in or outside the vessels upon the nervous centres in the cord. It is not probable that where recovery takes place there has been rupture of the vessels and consequent haemorrhage, though in those cases in which there is no recovery but in which the patients remain paraplegic it would appear that this is what happens. In the foregoing case the pressure on the cord was certainly not due to haemorrhage because the man was at once completely cured by re-compression, and had the "locking-out" occupied an hour instead of less than ten minutes I am perfectly satisfied that there would have been no return of the paraplegia. When I saw the man nearly 48 hours had elapsed, and he was probably then suffering not so much from the pressure as from the results of that pressure on the nervous structures of the cord, but from the fact that the second re-compression was of some benefit there was probably some free air even at that time.

—In "The Lancet."

Compressed Air in Mining.

J. E. BELL.

When compressed air is metered, or compressors are rated, the measurements are generally in cubic feet of free air. By this is meant the volume in cubic feet the air occupied before it was compressed; in other words, the volume at atmospheric pressure and temperature. Free air is a convenient way to reckon the quantity of air used by a drill or air motor, for the cost per 1,000 cubic feet of compressing the air can be easily determined. If the air is at atmospheric temperature, the quantity used for a given amount of work performed will not vary with the temperature.

The cost of operating motors is generally for comparison reduced to cost per H. P. hour, but in mining compressed air is principally used for rock drills, and a more satisfactory unit for estimating cost of operation is the cost per drill shift—*i. e.*, the cost of compressing the quantity of air used in the operation of the drill for one shift of eight hours. This does not mean the continuous operation of the drill for the whole period of eight hours, but only for such a time as in practice the drill is in use, probably averaging the equivalent of from four to five hours of continuous operation.

The cost per drill shift can be readily ascertained at each mine, by keeping account of the number of shifts the drills were used during the month, and dividing the cost of the operation of the compressor for that time by this number of drill shifts. This cost will, of course, vary

with the size of the drill, but as the different sizes use air at a rate approximately proportional to the square of their diameters, all sizes can be reduced to one standard size. In what follows, a three-inch drill is taken as the standard, and with this unit a two-inch drill, for example, would use 4/9 of the quantity of air used by the standard drill.

A large number of experiments to determine the quantity of free air used per drill shift were made not long ago by Mr. L. L. Summers, of Chicago, and the writer. The results showed that the quantity of air varies between 35,000 and 60,000 cubic feet. The character of the rock affects the result to some extent, as does also the quantity of air used for driving out the gases produced by explosives. The consumption already mentioned is for air furnished at 100 lbs. gauge pressure, and at an altitude of 10,000 feet above sea level. The consumption per drill shift varies with the altitude, but can be readily calculated for other elevations.

If P is the gauge pressure of the compressed air in lbs. per square inch, and a is the atmospheric pressure, then P+a is the total or absolute pressure per square inch, which will sometimes be represented by p. Let V represent the number of cubic feet occupied by one pound of the air; then

$$(P + a)\ V = pV = .37\ T.$$

In this formula T is the absolute temperature or the Fahrenheit temperature in degrees + 461°. This formula can be used for calculating the weight of one cubic foot of air at pressure p and temperature T, for this is equal to 1/V or p .37 T. Approximately, the atmospheric pressure per square inch a is equal to

15 lbs. at sea level.
12 lbs. at 5,000 ft. elevation.
10 lbs. at 10,000 ft. elevation.

By taking p as equal to a, the weight of 1,000 cubic fee of free air at any altitude can be calculated, and is equal to

$$1000\ V = \frac{1000\ a}{.37\ T}$$

If T is taken to be 461+60=521, this will give for the weight of 1,000 cubic feet of free air at different altitudes:

77.7 lbs. at sea level.
61.2 lbs. at 5,000 ft. elevation.
51.8 lbs. at 10,000 ft. elevation.

An air drill is practically an engine taking air full stroke, and hence the mean effective pressure is P lbs. per square inch, and the work done per stroke is 144 P times the volume of the drill, and as the compressed air used per stroke is equal to the volume of the drill, the work in foot pounds done in any given time is equal to the pressure per square foot, or 144 P times the volume of the compressed air used, where this volume is in cubic feet. A deduction from this is that if the gauge pressures are equal, a drill will use the same number of cubic feet of compressed air per drill shift at any altitude. As both P and the work are the same for the different altitudes, 144 P V is the work done.

The volume of free air used is to the volume of compressed air used as a+P is to a. Hence

$$\text{Free air} = \frac{a + P}{a}\ \text{(vol. comp. air.)}.$$

When P=100 and a=10, the free air per drill shift varies from 35,000 to 60,000 cubic feet. Hence, the compressed air would vary from 3,200 to 5,500 cubic feet per drill shift. By substituting these values in the equation, the free air for any altitude can be caluculated:

Cubic feet of free air used per drill shift:

25,000 to 42,000 at sea level.
30,000 to 49,000 at 5.000 ft. elevation.
35,000 to 60,000 at 10,000 ft. elevation.

These results were obtained with a gauge pressure of 100 lbs. per square inch. The consumption of compressed air will vary with the gauge pressure. The work done by the drill will also vary according to the pressure, and as 100 lbs. pressure seems to give the best results, it has been taken as a standard pressure.

The capacity of a given compressor at different altitudes is proportional to the number of cubic feet of free air required per drill shift for the drills operated by the compressor, and is reduced 18 per cent. at 5,000 feet elevation, and 30 per cent. at 10,000 feet elevation. Hence, if a compressor could supply 40 drills at sea level, it would be able to operate only 28 at 10,000 feet above sea level.

The work required to compress 1,000 cubic feet of free air to the gauge pressure P from the atmospheric pressure a

is given in foot pounds by the well-known formula:*

$$144{,}000\, a \frac{n}{n-1}\left[\left(\frac{a+P}{a}\right)^{\frac{n-1}{n}} - 1\right]$$

Compressed adiabatically, in one cylinder, n equals 1.41. For two stage compressors with intercooler, n=1.23, but with large intercooler and plenty of cooling water, n can be cut down to 1.17, which has been attained in practice. Taking P=100, the free air per minute, in which form it is better adapted for use, as compressors are usually rated on that basis.

Horse-power required to compress 1,000 cubic feet of free air per minute:

	Ordinary two-stage compressor.	Most efficient two-stage compressor.
Sea level.....	161.1 H.P.	153.1 H.P.
5,000 feet altitude.	145.7 H.P.	136.9 H.P.
10,000 feet altitude	130.6 H.P.	126.2 H.P.

TABLE 1.

Style of Compressor Used.	Capacity in cubic feet of (maximum) free air per minute.	Coal cost per H. P. H'r.	Total cost per H. P. H'r.	Cost per 1,000 cubic ft. free air compressed.			Cost per drill shift.		
				Sea level.	5,000 ft. altitude.	10,000 ft. altitude.	Sea level.	5,000 ft. altitude.	10,000 ft. altitude.
Simple Steam..... (Non-condensing.)	150	2.1c.	4.0c.	10.8c.	9.6c.	8.7c.	$3.67	$4.00	$4.35
Simple Steam..... (Non-condensing.)	200	2.0	2.2	5.9	5.3	4.8	2.07	2.22	2.40
Compound Steam..... (Non-condensing.)	300	1.4	2.4	6.5	5.8	5.3	2.26	2.43	2.62
Compound Steam..... (Non-condensing.)	300	1.3	1.5	4.0	3.6	3.3	1.40	1.51	1.65
Simple Steam..... (Condensing.)	2,500	.5	1.0	2.7	2.4	2.2	.95	1.01	1.10
Compound Steam ..... (Condensing.)	3,000	.3	.8	2.2	1.9	1.8	.76	.81	.88
Central Plant ..... (Calculated.)	16,000	.3	.5	1.3	1.2	1.1	.47	.50	.55

Cost of drill shafts are for work in rock such as granite, etc.
Compressors in all cases are two stage intercurled.

work of compressing 1,000 cubic feet of free air at different altitudes is as follows, the results being in foot pounds:

	Ordinary two-stage compressor.	Most efficient two-stage compressor.
Sea level.....	5,316,000	5,053,000
5,000 feet altitude..	4,807,000	4,518,000
10,000 feet altitude.	4,310,000	4,160,000

This can be reduced to the horse-power required to compress 1,000 cubic feet of

*Unwin's "Development and Transmission of Power," page 174-5.

When the compressor is driven by steam, the power indicated in the steam cylinder will be about 18 per cent. more than the power needed to compress the air. The mechanical efficiency of compressors is about 85 per cent. Actual tests made with a small compressor gave 84 per cent. efficiency, while with a 35-drill Corliss cross-compound steam and air compressor, 86 per cent. efficiency was obtained. Making this addition, the indicated steam horse-power for compressing 1,000 feet of free air per minute is:

	Ordinary two-stage compressor.	Most efficient two-stage compressor.
Sea level.....	190.0 H.P.	180.7 H.P.
5,000 feet altitude.	171.9 H.P.	161.5 H.P.
10,000 feet altitude	154.1 H.P.	148.9 H.P.

The accompanying table on costs of compressed air and of operating drills will now be readily understood and applied. The first column describes the compressor used for compressing the air. The second gives its capacity in cubic feet of free air per minute. The third shows the actual coal cost per horse-power hour, as indicated in the air cylinder, and the fourth the total cost per horse-power hour, including labor, etc. The fifth and sixth give the cost of compressing 1,000 feet of free air to a gauge pressure of 100 lbs. per square inch, and the cost per drill shift at different altitudes.

The cost per horse-power hour for the power expended in compressing the air will vary with the charges for coal, labor and, in some cases, water. The figures in the table have been obtained from actual tests at mines in this country where coal costs from $3 per ton for run of mine to $5 per ton for lump. The lump coal was generally used, as on account of its higher evaporative power and the ease with which it could be handled, it gave more economical results.

The first data in the table were taken from a small compressor used in tunnel work. Both labor and coal charges are high in this case, as an engineer was needed exclusively for the compressor, and his entire time was charged to the cost per horse-power hour. In the second example, labor was not an item, as the fireman required for the steam hoist attended to the compressor. The variation between examples three and four is also due to labor. Example five shows the results of a test at one of the largest gold mines in the United States. Example six was from a compressor operated in connection with an electric power plant, furnishing air for a number of adjacent properties. Although in reality from a central plant, these last results can be taken as the limit of economy of compressors located at the shaft house of a mine.

The figures for a central plant are about what might be expected if a number of mining companies were to unite in erecting a large station, capable of supplying them all with compressed air. This plant would have a central location and the air would be carried to the different shafts by underground pipe lines. The losses in air transmission are not taken into account in the table, but they are figured out below.

When the compressed air is used in a hoist, pump or any sort of piston engine, the number of cubic feet of compressed air taken in at any time is equal to the volume of the cylinder multiplied by the ratio of cut-off and by the number of strokes in that time. If the air is used at the atmospheric temperature, the equivalent number of cubic feet of free air can be found from the formula already given. When, however, the compressed air is at some other temperature, T′, it is seen that its volume is in the ratio of T′/T to the volume of an equal weight of compressed air at the same pressure, but at the atmospheric temperature, T. Hence,

$$\text{Vol. free air} = \left(\frac{a+P}{a}\right)\left(\frac{T'}{T}\right)(\text{vol. comp. air}).$$

The number of cubic feet of free air used being known, the cost of operation can be determined from the cost per 1,000 cubic feet of free air.

From the formula just given, it is seen that the higher the temperature of the air used, the less is the amount of free air required, and the greater the efficiency. When not reheated, the highest temperature at which the air can be worked is that which it has when it leaves the compressor. In practice, the heat of compression is lost in the pipe line between the compressor and the motors or drills.

The advantages of reheaters are evident, but they cannot be used underground on account of the gases arising from combustion. When the air is piped to the shaft from a central plant, a reheater can be used at the surface, but ordinarily this will not raise the temperature of the air at the point where it is used.

In mining, compressed air is seldom used at a point nearer to the compressor than a thousand feet, and in many cases it is transmitted a number of miles. For this reason the losses in the pipe line are important and often have to be figured out.

In passing through the pipe the air will cool, with a reduction of volume, the pressure will drop on account of the friction due to the velocity, and a portion

will leak out at the joints of the pipe. Hence to deliver a required amount of air a larger quantity must be compressed to a greater pressure and heated to a higher temperature. This requires an expenditure of energy, and such extra work will be lost in the pipe line.

The cooling of the air is unavoidable, even in a short length of pipe. As such loss occurs whenever compressed air is used in mining, it need not be figured in the transmission losses. It is well to note, however, that when reheaters are used this loss can be cheaply replaced.

When the pressure drop is known, the loss by friction in the pipe can easily be calculated. If P_1 is the inlet gauge pressure, and P_2 the outlet pressure of the air in the pipe, the loss per 1,000 cubic feet of air transmited is, evidently, the extra work required to compress the air to the pressure P_1 over that required to compress it to the gauge pressure P_2. Hence substituting first P_2, then P_1, in the formula for the work of compression and subtracting, gives:

Work in foot-pounds lost in transmitting 1,000 cubic feet of free air =

$$144{,}000a\frac{n}{n-1}\left[\left(\frac{a+P_1}{a}\right)^{\frac{n-1}{n}}-\left(\frac{a+P_2}{a}\right)^{\frac{n-1}{n}}\right]$$

a is the atmospheric pressure and n the constant of compression for which values have been given.

The work which the air will do after delivery depends upon the pressure P_2; hence the increased cost of the compressed air due to pressure drop in transmission is

$$100\frac{(a+P_1)^{\frac{n-1}{n}}-(a+P_2)^{\frac{n-1}{n}}}{(a+P_2)^{\frac{n-1}{n}}-(a)^{\frac{n-1}{n}}}\text{ per cent.}$$

In the application of this formula table II. has been calculated. The figures are for a delivery pressure of 100 pounds per square inch, and are given for different elevations. The first column is the pressure drop in the pipe, in per cent. of outlet pressure (100 pounds). The other three columns are per cent. energy lost in transmission due to the drop in pressure of the first column.

TABLE II.

FRICTION LOSS IN PIPE LINE.

Pressure drop in per cent. of delivery pressure.	Loss in pipe line in per cent. ——of energy delivered.—— Sea level.	5,000 feet elevation.	10,000 feet elevation.
15	7½	7⅛	6¾
10	5	4¾	4½
5	2½	2⅜	2¼
2½	1¼	1 3-16	1⅛

The figures given are correct for values of n between n = 1.17 and n = 1.23.

It is seen from the table that the loss of energy is only about half the drop of pressure. (In electrical transmission they are equal—i. e., the voltage drop is equal to the per cent. loss of energy.)

The loss of air by leakage through the joints in the pipe is not generally appreciated. This is probably due to the fact that the most reliable data on compressed air transmission have come from plants in which the air mains are of a large size and hence have a small leakage loss in proportion to the amount of air passing through them. In mining it is more serious, as the air mains are seldom more than 6 inches in diameter and often 2-inch lines of considerable length are put in.

The loss on account of pressure drop occurs only while the compressed air is being used, but the loss by leakage is continuous throughout the time the air under pressure is in the pipe. It is independent of the amount of air passing and depends only upon the pressure, the form and condition of the threads on the pipe and the manner in which the joints are made up. It can be quickly and accurately determined by attaching a pressure gauge to the pipe line and noting the fall in pressure per minute, when both the inlet and outlet valves have been tightly closed, with the line full of compressed air. If p is the initial absolute pressure per square inch, p^1 the pressure after one minute time, f the difference between the two or the drop per minute, and C the volume of the pipe line in cubic feet, then the weight of the air in the pipe line to start with is in pounds:

$$\frac{pC}{.37T}$$

where T is the absolute temperature in Fah. degrees. The weight of the air in the pipe one minute afterward is:

$$\frac{p^1C}{.37T}$$

Hence the weight of the air leaked out and lost during the minute is:

$$\frac{(p-p^1)\,C}{.37T}$$

or, reduced to cubic feet of free air, it is:

$$\frac{(p-p^1)\,C\,.37T}{.37Ta} = \frac{fC}{a} \text{ cu. ft. of free air per minute.}$$

If l is the length of the pipe line in feet, d the diameter of the pipe line in inches, then

$$C = \frac{.7854}{144} - d^2l = .005d^2l.$$

Consequently the loss per foot per minute is:

$$.005\frac{fd^2}{a}$$

The drop per minute as shown by the gauge, is independent of the length of the line, but depends upon the perimeter of the pipe and also in a measure upon the number of threads screwed into the coupling. If the number of threads were the same in all sizes of pipe the leakage would vary as 1/d. As the small sizes of pipe have fewer threads and as the number of threads varies roughly as the diameter, it would seem that the loss of pressure per minute would vary inversely as the square of the diameter. Although experiments give results between rather wide limits the mean values conform approximately to this relation. The following results are taken from tests and represent about the limit of the drop in pressure allowable. These must be taken as approximate results only, but will be found useful in figuring possible losses.

LEAKAGE TEST.

At 100 pounds per square inch:

2-inch pipe, pressure drop per minute, 3 pounds.

2½-inch pipe, pressure drop per minute, 2 pounds.

3-inch pipe, pressure drop per minute, 1.3 pounds.

4-inch pipe, pressure drop per minute, .75 pounds.

Since the pressure drop or f is inversely proportional to the square of the diameter of the pipe, the loss per foot of pipe, which is proportional to fd^2, will be independent of the diameter of the pipe. Hence substituting the value of f and d given in the formula, the loss in cubic feet of free air per minute in a pipe of length l is :

$$= .005\frac{21^2\times 3}{a}l = .06\frac{l}{a}$$

At sea level this gives .004Xl; at sea 5,000 ft. elevation, .005Xl; at sea 10,000 ft. elevation, .007Xl.

As an example, a pipe 5,000 feet long, at sea level, would lose 20 cubic feet of free air per minute, or 29,000 cubic feet of free air per day. This at 5 cents per thousand would mean a loss of $1.45 per day. If the pipe was large and a large number of drills were supplied, this would hardly be noticeable, but if only one or two drill shifts were furnished it would add quite materially to the cost of power.

Before the loss in a pipe line can be calculated the pressure drop must be known. This, for a given velocity, can be determined by experiment, provided there is some accurate means of measuring the velocity of the air in the pipe. In most cases it will be found better to calculate the drop from a reliable formula. Practically, this is rendered difficult by the obscure and often inaccurate manner in which the formula and constants are given in text books and reference works.

In a short length of pipe, if p is the inlet velocity and p_2 the outlet velocity, it has been found by well-known experiments that,

$$(A)\ p_2 = (1 - .00000014\frac{v^2 l}{d})\,p_1$$

where v_1 is the initial velocity in feet per second of the air in the pipe; l, the length of the pipe in feet; and d, the diameter of the pipe in inches.

In this formula and in the following, the air in the pipe is supposed to remain at a constant temperature (that of the ground,) and where it enters into the constants it is taken to be 60 degress F.

As the air passes through the pipe the pressure diminishes, and as a consequence the volume of a given weight increases, and hence the velocity must increase, and so for accurate results the formula just given is not applicable. This formula does not take into account the leakage, which tends to make the initial velocity greater. If the increase of velocity is taken into account,

$$(B)\ p_2 = p_1\sqrt{1 - .00000028\frac{v_1{}^2 l}{d}}$$

With leakage also figured on the basis given. *(*See note.*)

$$\text{(C)}\quad p_2 = p_1\sqrt{1-.00000028\frac{v_1, {}^{2}l}{d}\left(\frac{1}{{}^{5}v,p,d^2}\right)}$$

The number of cubic feet of compressed air delivered per second is the velocity times the sectional area of the pipe, or

$$.7854\, v\left(\frac{d}{12}\right)^2$$

and if expressed in cubic feet of free air is

$$.0055\frac{v\, d^2\, p}{a}$$

If this is represented by Q, then

$$v = 182\frac{Q\, a}{d^2\, p}$$

It is to be noted that v_1 is the initial velocity; in practice the final velocity determined from the quantity of air delivered is what is given; calling this v_2, then

$$v = v_2 + .18\frac{1}{d^2\, p}$$

A 3-inch drill when working at 100 pounds gauge pressure takes about 110 cubic feet of free air per minute at sea level, 130 at 5,000 feet altitude and about 155 cubic feet at 10,000 foot elevation. This would make a velocity in the pipe line for any altitude of

$$v = 182\frac{(110/60)\ 15}{115\, d^2} = \frac{43.3}{d^2}$$

As an example of these formulae, the pressure drop in a 4-inch pipe 5,000 feet when it is supplying eight 3-inch drills, will be calculated.

The outlet velocity will be

$$v_2 = \frac{43.3 \times 8}{16} = 21.7$$

Hence

$$v_1 = 21.7 + .18\frac{5000}{16 \times 115} = 22.2$$

By formula (A) since $p^2 = 115$

$$p_1 = \frac{115}{1 - .00000014\dfrac{21.7^2 \times 5000}{4}} = 125.6$$

By formula (B)

$$p_2 = \frac{115}{\sqrt{1 - .00000028\dfrac{21.7^2 \times 5000}{4}}} = 125.8$$

By formula (C) leakage taken in

$$p_2 = \frac{115}{\sqrt{1 - .00000028\dfrac{22.2^2 \times 5000}{4}\left(1 - \frac{1}{5}\dfrac{5000}{22.2 \times 115 \times 16}\right)}}$$

It is evident from this example that the more accurate formulae (B) and (C) are not necessary unless the pipe line is very long. Formula C can be thrown into a form betted adapted for use:

Pressure drop in pounds per square inch

$$= .00000014\frac{v_2,\ p_1\ l}{d}$$

When the air taken into the compressor carries water vapor, a portion will be condensed in the intercooler, but some will be carried through and condensed in the pipe line as the air cools. If this water of condensation is not drained out it will be carried through to the drills. The temperature of the air, when discharged from the drill, has been lowered on account of expansion against the resistance of the exhaust ports and passages, and if any amount of water is carried through it will freeze and be apt to clog the drill. Traps can be placed at the low points of the system, but where possible it is best to slope the pipes after leaving the air compressor so that the condensed water will drain back to a receiver placed near the compressor. This obviates danger of freezing up of pipe lines in winter, for the condensed water will not have to pass through pipe or air of a freezing temperature. A leak in a pipe line, such as a defective gasket at a coupling, will sometimes freeze up the pipe at that point, if the air is not dry, the reason for which is evident.

If air saturated with moisture is taken into an intercooled compressor, at a temperature of 60° F., and is compressed to 100 pounds gauge pressure, about five-eighths of the moisture in the air will be precipitated in the intercooler and about one-sixth in the pipe line. This per 1,000 cubic feet of free air compressed would give .5 pound condensed in intercooler and .14 pound in pipe line.

Of late years electricity has had many applications in mining. Thus far its use in driving rock drills has been rather unsuccessful, from a mechanical standpoint, although great claims are made for it on the ground of economy. The basis on which these claims are made in some cases are fictitious and in nearly all cases do not give compressed air a fair showing.

If electricity was applied to rock drills, it would be generated at a central plant, driven by either water power or steam. Water power in most cases is not available, so the central station would be operated by steam. Therefore, for a just comparison between electricity and compressed air, the air must be compressed in a central station, by engines allowing as high economy as those used in driving the electrical generators.

To drill a given number of holes a given depth, the same work is required, whether the drill is operated by electricity or by compressed air, and if, in both cases, it is done in the same time, the power developed is the same. Starting in both cases with this unit of power, and tracing the losses till the steam cylinder at the central plant is reached, will give a fair statement of their comparative economy. Another way to get at the matter is to begin at the steam cylinder and calculate the efficiency in delivering power to the hole in the rock. The latter is the more convenient.

The output of an air compressor depends upon the number of revolutions it makes per minute, and changes in the load are met by varying the number of revolutions. As a consequence of this method of governing, the power spent in overcoming internal friction will vary directly with the load. Hence, the mechanical efficiency is independent of the load. in practice, with a good compressor, it will be 86 per cent.

It has been shown that the efficiency of transmission of compressed air will be at least 90 per cent.; in fact, it would be poor engineering that would not make it higher. For comparison with electricity 90 per cent. will be considered the efficiency from the compressor to the drill.

At sea level 1,000 cubic feet of free air is equal to 130.5 cubic feet of compressed air at 100 lbs. gauge pressure. This will do 144x100x130.5=1,880,000 foot-pounds of work in an air drill. It would take 5,053,000 foot-pounds to compress the air, and hence the efficiency of the drill is 1,880,000/5,053,000=.37, or 37 per cent.

The actual efficiency of the power spent in the steam cylinder for rock drilling by compressed air is evidently now .86x90x .37=.287, or 28.7 per cent.

Engines driving electrical generators do not vary their speed with the load. Hence, the power spent in internal friction is constant at all loads, and as a result the mechanical efficiency decreases with the load. The mean mechanical efficiency will be lower than the efficiency at full load.

For a varying load, such as is encountered in mining work, a mean mechanical efficiency of 85 per cent. would be a good result. The mean electrical efficiency of the generator, figuring in exciters, etc., is about 90 per cent. The efficiency of electrical transmission, taking into account losses in the line and losses in transformers, would not exceed 90 per cent., and, lastly, the mean efficiency of a small motor such as would be required to operate a drill would be about 60 per cent. Combining these results, the actual efficiency of an electric drill would be .85x 90x.90x.60 = .413, or 41.3 per cent.

If the power cost per indicated h. p. was the same in both instances, the economy of electricity over compressed air would be in the ratio of 41.3 to 28.7. The conditions of economy are, however, not identical. The compressor operates at practically a fixed cut off and secures the most economical expansion of the steam at all loads. The generator engines only equal the compressor engines in economy at full load and with the varying load in mining work would be markedly more economical.

Another point to be noted is that the capacity of the pipe lines and receivers would dampen rapid fluctuations and tend to flatten out the load curve in an air plant, which would be conducive to economy. In many ways an air-compressing plant resembles a pumping station, and the economy of these, when compared to electric power plants, is well known.

All things considered, the cost per indicated horse power in a large air-compressing plant could be made with a conservative estimate of 75 per cent. of the cost in an electric plant of a like size.

It is apparent from this that the cost of operating electric drills is about the same as for air drills; so from the standpoint of economy the air drill has nothing to yield to its competitor. When its present state of perfection, its comparative light weight and its usefulness as a ventilator are taken into account, it looks is if it had many more years of usefulness.

Formulae (B) and (C) can be deducted from formulae (A) as follows:

From (A)

$$d\,p = -.0000014\frac{v^2\,p}{d}\,d\,l$$

The amount lost by leakage from the length l is

$$k\frac{l}{a} = .001\frac{l}{a}$$

but this must equal the difference between the amount entering and the amount leaving the pipe. Hence

$$\frac{k\,l}{a} = .0055\frac{d^2}{a}(p.\,v. - p\,v)$$

and

$$v = \left(182\frac{k\,l}{d^2} - p.\,v.\right)/p$$

Substituting in the formula for pressure drop gives

$$dp = -.0000014\frac{\left(182\frac{k\,l}{d^2} - p\ v.\right)^2}{d\,p}\,d\,l$$

or neglecting the square of k

$$p\,d\,p = .0000014\frac{p.^2v.^2}{d}d\,l - .0000014\ \frac{364\,k\,l\,p.\,v.}{d^2}\,d\,l$$

Integrating this and

$$p^2 = .00000028\frac{p.^2v.^2\,l}{d} - .0000014\frac{364kl^2p.v.}{d^2}$$

When $l = o$, $p = p$, hence $c = p^2$ therefore

$$p = p.\sqrt[l]{1 - .00000028\frac{v.^2l}{d}\left(1 - 182\frac{kl}{p.v.d^2}\right)}$$

If $k = o$ this gives formula (B) and if $k = .001$ it is (C).

Formula (B) is deducted in another manner in Prof. Unwin's "Development and Transmission of Power."

—Mining and Metallurgy.

The Pohle Air Lift Pump and Taylor Hydraulic Air Compressor.

BY GEO. S. DILLMAN.

The Pohlé Air Lift is a system of pumping water from artesian wells by means of compressed air. It has the advantages of pumping more water and with greater reliability than any other system. It also purifies the air. Sand or grit does not affect its operation. The Taylor Air Compressor is a system of compressing air by means of falling water, the free air being taken in at the top and is compressed with the water in passing down the downflow pipe. Properly speaking, one is the reverse of the other.

In the air lift the efficiency decreases as the lift increases, while in the Taylor Air Compressor the efficiency increases as the fall increases. Both, however, have a limit.

In the Pohlé Air Lift case, air expands isothermally. In the Taylor Air Compressor, it is compressed isothermally. This curve of expansion or compression is expressed by the formula

$$y = \frac{an}{n+1}\left(\log e\ \frac{n(1-x)}{x} - \frac{1}{x}\right) - a$$

where y = depth below efflux or influx, in feet.

a = height of a column of water balancing the atmosphere, feet.

n = ratio of areas of air to water at efflux or influx.

and x = ratio of areas of air to water at depth y.

This curve bears the same relation to the mathematics of either of them that the curve of expansion of steam in a cylinder does to the mathematics of steam engineering.

Following up the application of this formula proves that the efficiencies vary alike. It is increased by increasing velocity up to the point where friction offsets it. A further increase in velocity decreases efficiency. The point of maximum efficiency for any proposed installation is absolutely fixed.

The maximum pressure useful in the air lift or possible in the compressor is the depth of submergence plus friction of flow. While air lifts are pretended to be operated with greater pressure, such increase only represents loss and decreased efficiency of the whole. It must be controlled by valves to have it at all.

Patents have been granted both of them, not one of which is pertinent to their operation. Most of them are detriments to highest efficiency.

Finally, they are both old. The ancient Trombe is identical with the Taylor Air Compressor, having the same vertical pipe taking air in with the water, the separation chamber, the separate discharge pipes from the separation chamber. Eubanks says "The Trombe is of considerable antiquity. It was known to Heron, and is referred to in Pliny's Natural History. Kircher has given several figures of it, etc., etc."

The Air Lift is perfected by Nature in a spring in Kissingen, Bavaria. It is operated by Nature in all the geyser springs in the world. The gases may not be air, but they are insoluble and non-condensing at the temperatures used. Improperly installed air lifts sometimes produce beautiful geysers, too. The artificial air lift was first used in 1766, at least, that is the earliest record at hand. It was then adduced as proof that the atmosphere could sustain a vertical column of water greater than the theoretical 34 feet. Its investigation, however, showed otherwise. The report says "It was ascertained that the air, on entering the pipe, became mixed with the water; which, therefore, instead of being carried up in an unbroken column, was raised in disjointed portions or in the form of thick rain. This mixture, being much lighter than water alone, a longer column of it could be supported by the atmosphere, and by proportioning the quantity of air admitted, a column of the compound fluid may be elevated one or two hundred feet, etc., etc."

The saying that "There is nothing new under the sun" seems to apply to Air Lifts and Hydraulic Compressors.

Notes.

The eighth annual convention of the Air Brake Association will be held in Chicago, April 30, 1901.

H. K. Porter & Co. have received an order for nine compressed-air locomotives from the Anaconda Copper Company, of Montana.

Recent reference to the Caskey Portable Pneumatic Punch has interested many machine-tool users. This machine has merits that appeal to the most discerning among machinists, and there is anticipated a strong demand for it. The Pike & Child Company, Bourse Building, Philadelphia, is agent for marketing this punch.

We are advised that the Quick as a Wink Hose Coupling, having been found to be a time saver in shops where compressed air is used, is now coming into general use on hose for pneumatic tools and machines. Frick & Lindsay, of Pittsburg, Pa., who deal largely in pneumatic hose, have contracted with the W. J. Clark Company, Salem, Ohio, for a continued supply of the Quick as Wink couplings for such purpose.

In relation to the independent motors in use on Twenty-eight and Twenty-ninth streets, experts were quoted in Wall street as saying that construction and equipment should not cost to exceed $18,000 to $20,000 a mile, and that it can be laid at night, block by block, surfaced up by daylight, and in no way interrupt the general traffic of the city. It is claimed beyond all this that the independent motors can run anywhere in the city over any tracks, and any injury to one or more will not interfere with the regular transportation of the passenger business on all other cars in service.

A handbook of air compressing and allied machinery and tools has been issued by the Clayton Air Compressor Works, 26 Cortlandt street, New York. It describes the general design of the different types of compressors and vacuum pumps and explains their special features in detail. There are also notes on air compressing generally, liquefying carbonic acid gas, the air lift, pneumatic tools, and some valuable tables on air compression at high altitudes and the flow of air in pipes. The book is handsomely printed on heavy paper and is profusely illustrated with half-tone cuts.

A new type of air compressor designed primarily to keep down the temperature of the air during compression is described in a pamphlet just issued by the Havana Bridge Works, Montour Falls, N. Y. It has a very large amount of cooling surface, not only in the air cylinder, but also in the piston and in the inlet passages, the latter being fitted to cleanse as well as cool the air. The double-stage compression is effected in a single cylinder by the use of a differential plunger-piston. The steam end has both automatic and air-pressure governors, which are described fully. The pamphlet also contains illustrations of pneumatic riveting machines and hammers.

It has been noticed that if liquid air be allowed to evaporate freely the nitrogen in it passes away more quickly than the oxygen, and that consequently the final product is a gas very rich in the latter element. A German engineer, named

Hemple, proposes to utilize this property in the combustion of low-class fuels such as lignite and peat, and has constructed a furnace for that purpose. At a proper distance from the latter the liquid air is allowed to vaporize, and the first vapors, rich in nitrogen and poor in oxygen, are separated, while those coming later, containing as much as 50 per cent. of oxygen, are led under the grate bars, with the result of greatly intensifying the combustion.

The altitude above sea level at which an air compressor is to operate is an important point, the air being less dense at an elevation than at the sea level. When working at an elevation the compressor takes in less air at each revolution than at a lower level, its capacity is diminished, and there is a corresponding reduction in the power required to operate it. Following is a table showing the efficiency and loss in capacity of compressors working at different altitudes. It is computed for air compressors delivering air at sixty pounds pressure per square inch.

Altitude above sea level, feet.	Barometer, inches.	Efficiency of compressor, per cent.	Loss, per cent.
0	30.00	100.0	0.0
500	29.42	98.4	1.6
1,000	28.85	96.9	3.1
1,500	28.34	95.5	4.5
2,000	27.78	94.0	6.0
3,000	26.74	91.1	8.9
4,000	25.70	88.1	11.9
5,000	24.73	85.9	14.1
6,000	23.83	82.8	17.2
7,000	22.93	80.2	19.8
8,000	22.04	77.5	22.5
9,000	21.22	75.1	24.9
10,000	20.43	72.7	27.3

Sir Joseph Fayrer, who served a long time in India as Surgeon-General of the British Army, gives an account of the methed used by the Burmese natives in producing fire. Matches are unknown in many parts of the Orient; are not needed in fact, for most Oriental people are skilled in ways of obtaining flames through friction.

A Burmese messenger brought a note to Sir Joseph one day, and while he was writing the reply for the waiting man he noticed an object somewhat like a boy's popgun suspended by his waist. In reply to an inquiry, the native told him that it was an implement for producing fire, and gave a practical illustration of its working.

A small tube, several inches long and closed at one end, held a tightly fitted piston; the later was hollowed slightly at the lower end and smeared with wax to receive a bit of cotton or tinder, which adhered when pressed into it.

Placing a small wisp of cotton upon the wax the messenger fitted the piston into the tube, and forced it down by striking it a sharp blow. When it was withdrawn the cotton was on fire, having become ignited by the sudden concussion of the compressed air.

A pneumatic foundry riddle has been put on the market by E. E. Hanna, 751 Cullom avenue, Chicago. This screen shaker is a simple arrangement of a valveless piston working in a cylinder. The piston is directly attached to a holder, which is arranged to hold an ordinary 16-inch circular foundry riddle. The whole is mounted either on a tripod or on a frame which is to be held by sockets fastened to posts or building walls, and are known as the tripod machine and the post machine. The latter can be used as a stationary machine if desired and can then be run with steam as well as with compressed air. There is practically only one moving part, with no joints to work under reversing strains. The screens can be changed in a fraction of a minute. The machine will shake through a ½-inch mesh all the sand that two men will care to shovel, and will shake through a ¼-inch mesh all that one man should shovel. It uses about 20 cubic feet of free air per minute, and is designed to work at eighty pounds gauge pressure. The minimum cost of operation is about 1½ cents, and the maximum may run up to 7 1-5 cents for 1,200 feet, the amount that the screen shaker might use in an hour. The main advantage that is claimed for the machine is its portability. The ease with which it is moved permits of screening the sand just where wanted. The tripod machine weighs 100 pounds, and can be handled by one man, while the post machine weighs 50 pounds, and can be handled by a boy.

For many years now a constantly increasing proportion of the national food supply has been dependent on the preservation of meat and fruit in transport and

fruit in transport and storage by means of artificial cold, so that the subject of refrigeration is one of great and growing importance to the public. Within the last two years a more special interest has been exhibited in this and kindred subjects by the cheaper and more convenient production of liquid air, the proposed application of it, and the remarkable scientific discoveries to which it has led. There have, however, been many discordant views put forth, and confidence in the possibilities of the new agent has been rendered very hesitating by the fact that the most glowing of the promises held out have been put forward by those who were trying to promote companies based on the prospects of its usefulness. Those of the public who wish for authoritative guidance and an opportunity of getting clear ideas on the whole subject of refrigeration, will shortly have an opportunity placed within their reach. The Technical Educational Board of the London County Council, acting in conjunction with the Council of University College, London, have arranged for a series of lectures on the artificial production of cold, to be delivered in the Chemical Theatre of the College in Gower street by Dr. W. Hampson, whose apparatus for liquefying the air is well known in this country and on the continent. Young engineers and others, who are engaged in practical work in connection with refrigerating machinery or cold storage, and who have not had the advantage of a systematic training in the physical sciences, should find this a useful opportunity of learning to understand better the connection between their work and the scientific principles involved in it.

On account of the many explosions that have occurred in air compressors or their receivers, owing to gases generated from the burnt oil used for lubrication, the firm of Dryer, Rosenkranz & Droop, Hanover, has brought out a graphite lubricator resembling in outward form those used for oil. The cup, which may be closed at the top by an air-tight cover, is put in communication with the compressor cylinder by a bend with two-way cock, the upper vertical end of the bend being screwed into the bottom of the cup and the lower horizontal end into a special nipple or that for the indicator. The cock being closed and the cover removed, the cup is filled, or nearly so, with graphite dust, when the cover is screwed on and the cock opened. The compressing half of the piston stroke sends compressed air into the cup, whirling into a cloud the graphite dust, which, however, subsides when the pressure becomes equal in the cup and cylinder, thus closing the hollow bend. During the next exhausting half of the stroke the small quantity of compressed air left in the top of the cup above the graphite dust expands and sends a portion into the cylinder, the graphite being thus used economically, while at the same time all chance of explosion is avoided. It is advisable to fit a graphite lubricator at each end of the compressor cylinder, although one in the middle will serve the purpose; but in that case there is the disadvantage of a rather long length of small pipe, with its liability to be clogged.

The probable adoption of a new system of motive power by the Union Traction Company as soon as the question of franchise extension is settled will attract attention to the recent report of the Metropolitan Street Railway Company, of New York, which has just been published by the State Railroad Commission at Albany.

This report covers the operation of the Metropolitan Company's Thirty-fourth street cross-town line and the Twenty-eighth street cross-town line. The former line is operated by the storage-battery system, while the cars on the latter are run by compressed-air motors. The report offers an opportunity for comparison that cannot fail to be of great value to traction interests all over the country. The statement shows, among other things, that the use of storage batteries increased operating expenses during the quarter in the sum of $13,437, while compressed air reduced operating expenses by $7,651. It is also claimed that the cost of installation is in favor of compressed air, all of which makes a remarkably strong showing for this system of traction.

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It is barely possible that the traction development of the future will narrow

Hemple, proposes to utilize this property in the combustion of low-class fuels such as lignite and peat, and has constructed a furnace for that purpose. At a proper distance from the latter the liquid air is allowed to vaporize, and the first vapors, rich in nitrogen and poor in oxygen, are separated, while those coming later, containing as much as 50 per cent. of oxygen, are led under the grate bars, with the result of greatly intensifying the combustion.

The altitude above sea level at which an air compressor is to operate is an important point, the air being less dense at an elevation than at the sea level. When working at an elevation the compressor takes in less air at each revolution than at a lower level, its capacity is diminished, and there is a corresponding reduction in the power required to operate it. Following is a table showing the efficiency and loss in capacity of compressors working at different altitudes. It is computed for air compressors delivering air at sixty pounds pressure per square inch.

Altitude above sea level, feet.	Barometer, inches.	Efficiency of compressor, per cent.	Loss, per cent.
0	30.00	100.0	0.0
500	29.42	98.4	1.6
1,000	28.85	96.9	3.1
1,500	28.34	95.5	4.5
2,000	27.78	94.0	6.0
3,000	26.74	91.1	8.9
4,000	25.70	88.1	11.9
5,000	24.73	85.9	14.1
6,000	23.83	82.8	17.2
7,000	22.93	80.2	19.8
8,000	22.04	77.5	22.5
9,000	21.22	75.1	24.9
10,000	20.43	72.7	27.3

Sir Joseph Fayrer, who served a long time in India as Surgeon-General of the British Army, gives an account of the methed used by the Burmese natives in producing fire. Matches are unknown in many parts of the Orient; are not needed in fact, for most Oriental people are skilled in ways of obtaining flames through friction.

A Burmese messenger brought a note to Sir Joseph one day, and while he was writing the reply for the waiting man he noticed an object somewhat like a boy's popgun suspended by his waist. In reply to an inquiry, the native told him that it was an implement for producing fire, and gave a practical illustration of its working.

A small tube, several inches long and closed at one end, held a tightly fitted piston; the later was hollowed slightly at the lower end and smeared with wax to receive a bit of cotton or tinder, which adhered when pressed into it.

Placing a small wisp of cotton upon the wax the messenger fitted the piston into the tube, and forced it down by striking it a sharp blow. When it was withdrawn the cotton was on fire, having become ignited by the sudden concussion of the compressed air.

A pneumatic foundry riddle has been put on the market by E. E. Hanna, 751 Cullom avenue, Chicago. This screen shaker is a simple arrangement of a valveless piston working in a cylinder. The piston is directly attached to a holder, which is arranged to hold an ordinary 16-inch circular foundry riddle. The whole is mounted either on a tripod or on a frame which is to be held by sockets fastened to posts or building walls, and are known as the tripod machine and the post machine. The latter can be used as a stationary machine if desired and can then be run with steam as well as with compressed air. There is practically only one moving part, with no joints to work under reversing strains. The screens can be changed in a fraction of a minute. The machine will shake through a ½-inch mesh all the sand that two men will care to shovel, and will shake through a ¼-inch mesh all that one man should shovel. It uses about 20 cubic feet of free air per minute, and is designed to work at eighty pounds gauge pressure. The minimum cost of operation is about 1½ cents, and the maximum may run up to 7 1-5 cents for 1,200 feet, the amount that the screen shaker might use in an hour. The main advantage that is claimed for the machine is its portability. The ease with which it is moved permits of screening the sand just where wanted. The tripod machine weighs 100 pounds, and can be handled by one man, while the post machine weighs 50 pounds, and can be handled by a boy.

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fruit in transport and storage by means of artificial cold, so that the subject of refrigeration is one of great and growing importance to the public. Within the last two years a more special interest has been exhibited in this and kindred subjects by the cheaper and more convenient production of liquid air, the proposed application of it, and the remarkable scientific discoveries to which it has led. There have, however, been many discordant views put forth, and confidence in the possibilities of the new agent has been rendered very hesitating by the fact that the most glowing of the promises held out have been put forward by those who were trying to promote companies based on the prospects of its usefulness. Those of the public who wish for authoritative guidance and an opportunity of getting clear ideas on the whole subject of refrigeration, will shortly have an opportunity placed within their reach. The Technical Educational Board of the London County Council, acting in conjunction with the Council of University College, London, have arranged for a series of lectures on the artificial production of cold, to be delivered in the Chemical Theatre of the College in Gower street by Dr. W. Hampson, whose apparatus for liquefying the air is well known in this country and on the continent. Young engineers and others, who are engaged in practical work in connection with refrigerating machinery or cold storage, and who have not had the advantage of a systematic training in the physical sciences, should find this a useful opportunity of learning to understand better the connection between their work and the scientific principles involved in it.

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down to a battle between electricity and compressed air. Chicago has experimented to some extent with compressed air on the "owl cars" on the North Side lines, and the system is said to have worked very satisfactorily. It may be that the contest for supremacy will be between compressed air and the underground electric trolley system. But the latter involves great expense for installation, even where it is possible to utilize the cable conduit for the trolley wire. But here, again, compressed air has the advantage, for the reason that it makes every car independent of every other car.

Whatever may be the final judgment of the traction experts regarding the comparative merits of compressed air and electrical storage as motor powers, it is conceded that the street car of the future must be propelled by an independent motor device having no connection with other cars.

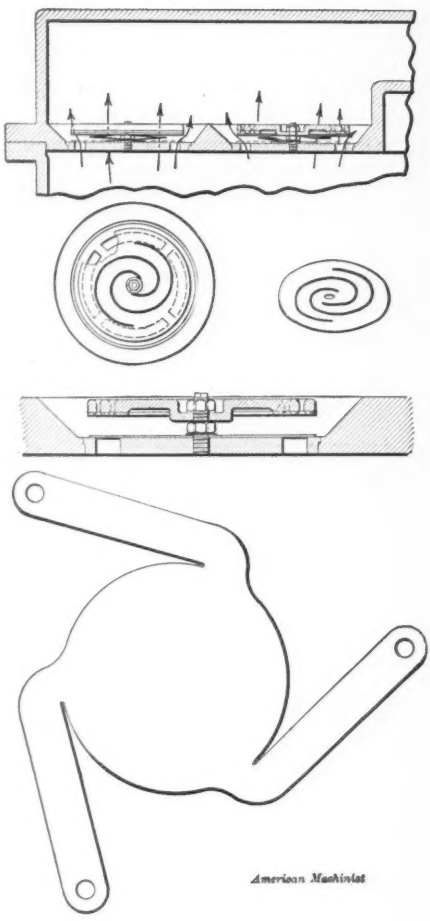
Korting's air-jet ventilator, which has been supplied to the Prussian State Mine Inspection authorities at Clausthal and Friedrichsthal, and also at the Harpen, Gelsenkirchen, Westfalia and other colleries, is intended for the separate ventilation of individual drifts and headings where there is a service of compressed air. The appliance is on the injector principle; but the action is multiplied three times the jet of compressed air drawing in one current, that a second, and the second a third, so that the useful effect is 20 per cent. greater than that of a sinple air jet for a short length of air pipes, while it is as much as 50 per cent. more for lengths of 200 m. (218 yards), and may be as much as 100 per cent. when the resistance increases with very long lengths of pipes. The air-jet ventilator was specially designed to afford the largest possible volume of air at atmospheric pressure for a minimum of compressed air employed, and also to permit of the readiest putting up, taking down, and shifting from place to place, while bends and angles do not greatly lessen the useful effect. The outlet end of the approximately cylindrical ventilator is merely inserted in the end of the zinc air-pipe; but when a wooden conduit is used, almost the whole length of the ventilator is inserted in it up to the flange, where the inlet or active portion is joined on, while the space between the two is carefully stopped up. According to the manner in which it is arranged in the air-pipe, this appliance acts as a pressure on an exhaust ventilator; and one can be made to serve for two branches of an air-pipe, in which case it is advisable to have a regulating valve in each branch. A central spindle in the ventilator regulates the consumption of compressed air, without, however, reducing its pressure. With a pressure of three atmospheres over atmospheric pressure size No. 2 of the air-jet ventilator—four are made—weighing 35 kilogs. (77 lb.), with a compressed-air pipe of 25 mm. (1 in.) and an air-pipe of at least 21 cm. (8½ in.) diameter, from 40 to 50 cubic metres (mean 1,590 cubic feet) of air are delivered short distances and 30 cubic metres (1,060 cubic feet) for air-pipe lengths of 100 m. (109 yards).

Reference has been made in the past to some of the advantages of applying compositions and paints generally to steamers by means of compressed air. We now hear that the system then spoken of, namely, that patented by Mr. J. Fell Redman, M. I. N. A., the superintending engineer of the Allan and Wilsons & Furness-Leyland Lines, has been successfully worked by the Mechanical Painting & Scaling Company, Limited. Compressed air at from 10 to 15 pounds pressure is conveyed in piping alongside the blocks in dry-dock the whole length of the steamer. At every 80 feet there are side connections, and pipes of 50 feet run from either side of the main piping to open tanks containing the composition. In each of these tanks there is a rotary pump and stirrer by which the paint is pumped up a 25-foot pipe to a patent nozzle, where it is met by compressed air, and is first atomized and then driven on to the ship in a fine spray. By this system the company has applied composition (of different makes) to the steamers Lisbon, 1,334 tons; Otarama, 3,800 tons; Anglian, 5,500 tons; Whakatane, 5,700 tons, and Bostonian, 4,700 tons, in Messrs. Fletcher, Son & Fearnall's dry docks, and in the Royal Albert dry docks, with great success, and to the satisfaction of many marine superintendents and others who have witnessed the work.

It is claimed for the system, and the operations referred to prove, that an even coating is applied, however uneven the surface, as the paint is driven into the smallest indentations in a manner impossible by brush work; that the coating can

be made to any desired thickness, with less waste of paint in considerably less time, and with a perfectly smooth surface; and that far better application can be made on wet surfaces, as the compressed air clears off moisture while driving the paint through to the surface to be painted. It is believed, now that the company has apparently overcome the worst of the many difficulties attending the introduction of this new system, that its many advantages will be quickly appreciated, and that it will be introduced on a large scale in this country and abroad. Fears were entertained by some that there would be trouble with the painters; these fears, however, have not been justified, as the ordinary painters have several times worked on other parts at the same time without raising any complaint. The company has also, we understand, successfully painted the inside of steamers.—*Fairplay.*

Mr. Julian Kennedy, of Pittsburg, who has done much in the development and improvement of blowing engines and air compressors, has recently devised and patented some interesting valves for this service, thus contributing to the mitigation of the most serious troubles encountered. The desirable features of such valves are that they shall be as light and have as little inertia as possible, and that they, with their appurtenances of springs and buffers, shall occupy also as little clearance space as possible. In the valves here shown these conditions seem to be as nearly complied with as possible. The idea embodied is simply that of making the valve and spring of a single piece of sheet metal. The seats of such valves are usually inserted into the cylinder head, so that they as well as the valves may be renewed when necessary. In the cut, at the top, is shown a section of a vertical blowing engine cylinder head with two valves in position. The valves are shown as raised against the buffers by the inrushing air. A plan of the valve and seat is given and an inclined view of one of the valves. The interior portion, cut spirally, forms the spring, and the valve proper consists of the outer ring. Below these is a larger section showing one of the valves in position and closed, while at the bottom is a suggestion for a valve of entirely different shape, also covered by the patent.



The Library Committee of the Brooklyn Engineers' Club, begs to announce the following informal discussion at the Library on Thursday evening, April 4th, "Compressed Air and its Uses," introduced by Mr. J. J. Swann, of The Ingersoll-Sergeant Drill Company, New York.

COMMUNICATIONS.

Under this heading will be published inquiries addressed to the Editor of COMPRESSED AIR. We wish to encourage our readers in the practice of making inquiries and expressing opinions.

We request that the rules governing such correspondence will be observed, viz.: all communications should be written on one side of the paper only; they should be short and to the point.

Compressed Air, New York City:

Gentlemen—Where can compressed air in cylinders be bought, suitable to ship by rail one hundred miles, and about what would it cost? Yours truly,

C. de P. FIELD.

U. S. PATENTS GRANTED FEB., 1901.

Specially prepared for COMPRESSED AIR.

667,185. TERMINAL FOR PNEUMATIC-DESPATCH TUBES. Charles H. Burton, Chicago, Ill., assignor to the National Pneumatic Service Company, same place. Filed June 20, 1900. Serial No. 20,925.

667,209. TERMINAL FOR PNEUMATIC STORE-SERVICE SYSTEMS. Hugo W. Forslund, Chicago, Ill., assignor to the National Pneumatic Service Company, same place. Filed Feb. 6, 1900. Serial No. 4,159.

667,224. AIR-PUMP. George W. Kellogg, Rochester, N. Y. Filed July 8, 1899. Serial No. 723,192.

667,229. PNEUMATIC MALTING APPARATUS. Friedrich Knuttel, Charlottenburg, Germany. Filed Oct. 20, 1900. Serial No. 33,773.

667,322. PNEUMATIC STRAW-STACKER. Ole O. Kittleson, Lee, Ill. Filed Nov. 5, 1900. Serial No. 35,563.

667,369. PNEUMATIC PAINTING APPARATUS. Joseph F. Redman, London, England. Filed Dec. 12, 1899. Serial No. 740,076.

667,630. PNEUMATIC ARROW. Henri O. Kratz-Boussac, Paris, France. Filed May 19, 1900. Serial No. 17,293.

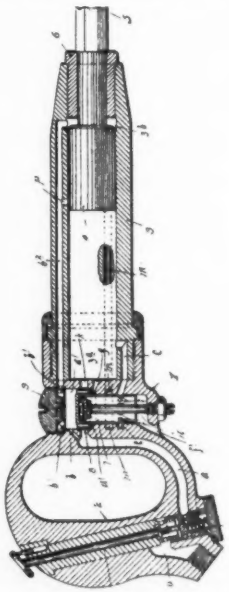
667,694. PNEUMATIC STRAW-STACKER. Thomas Goodale, Woodside, Minn. Filed Jan. 20, 1900. Serial No. 2,112.

667,784. PNEUMATIC HAMMER. John K. Lencke, Chicago, Ill. Filed April 2, 1900. Serial No. 11,146.

A direct-acting engine having a distribution-valve independent of and out of contact with the piston and having within its cylinder a compression-chamber with a passage leading to said distribution-valve, whereby the movements of said distribution-valve are controlled by pneumatic pressure generated by the momentum of the piston.

2. The combination with the cylinder 3 and piston 4, of the distribution-valve 7, 8, seated without said cylinder 3, ports leading to and from said distribution-valve and to the said cylinder, said cylinder having the compression-chamber 3a opening through a port g beneath the projecting ledge 8 of said distribution-valve.

3. The combination with the cylinder 3 fitted with the tool 5 and piston 4 and having in its ends the compression-chambers 3a and 3b, of the handpiece 2 secured



to said cylinder, equipped with a throttle-valve and provided with the valve seat, a^1, the distribution-valve 7, 8, seated in said valve-seat, and suitable admission and exhaust ports involving a supply-duct a, b, leading from said throttle-valve to said seat a1, the ports k, g, opening from seat a1 to said compression-chamber 3a, and the ports c, b2 leading from said distribution valve to the opposite ends of the cylinder.

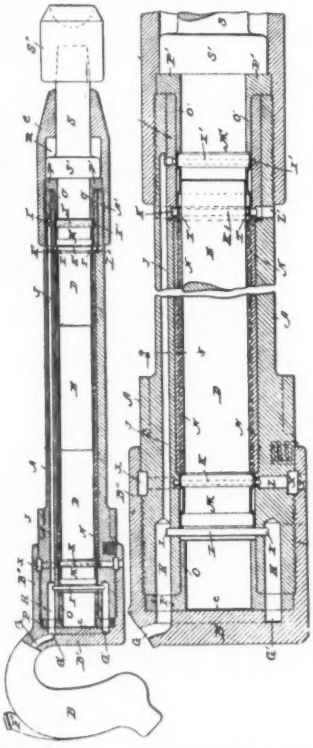
667,863. PNEUMATIC HAMMER. Joseph Boyer, St. Louis, Mo. Filed May 20, 1899. Serial No. 717,569.

A pneumatic hammer comprising a cylinder formed at its front end to receive and hold the shank of the working tool and having a grasping-handle secured to its rear end, a hammering-piston located in said cylinder and having a length of stroke greater than its own length, and adapted to deliver a blow to the shank of the working tool at the end of its forward stroke, and a valve controlling the reciprocations of said piston in said cylinder.

The combination of the cylinder A having the piston-chamber D, and inlet and exhaut ports at the opposite ends thereof, the valves (or two-part valve) M M′ located in opposite ends of the piston-chamber D and connected by the rods T T, and

the piston E reciprocating in the chamber D and operating at opposite ends of its strokes to shift the valves M M' by means of the air compresed in front of it.

The combination of the cylinder A having the piston-chamber D and provided with the inlet-passages H and groove I and exhaust-passages L and groove K, at its rear end, and the groove I' connected by the passage J with the inlet-pasasge H, and the groove K' and exhaust ports L', at its front end, the valves (or two-part valves) M M', the former located in the rear of the pis-



ton chamber and controlling the inlet and exhaust grooves I K, and the latter located in the front end of the piston chamber and controlling the inlet and exhaust grooves I' K', the rods T T interposed between said valves and the piston E reciprocating in the chamber D and operating to shift the valves M M' at the opposite end of its strokes by means of the air compressed in front of it.

The combination of the cylinder A having inlet and exhaust ports at opposite ends, the valves M M' controlling said ports, the bushing or sleeve N fitted within the cylinder A between the valves M M' and provided with the exterior longitudinal grooves, the wires T T located in the said grooves and co-operating at their opposite ends with the valves M M', the strips N' inlaid in the said longitudinal grooves and confining the wires T T therein, and the piston E reciprocating in the cylinder A (within the bushing N) and operating to shift the valves M M' at the opposite ends of its strokes by the air compressed in front of it.

667,948. PNEUMATIC SANDER FOR LOCOMOTIVES. John G. Neuffer, Madisonville, Ohio, and Robert Bennett, Edward Boas, and John Hair, Washington, Ind. Filed Aug. 30, 1890. Serial No. 28,619 .

668,152. AIR-BRAKE SYSTEM. Reuben B. Benjamin, Chicago, Ill., assignor of one-half to Rodney B. Swift, same place. Filed Feb. 5, 1900. Serial No. 4,087.

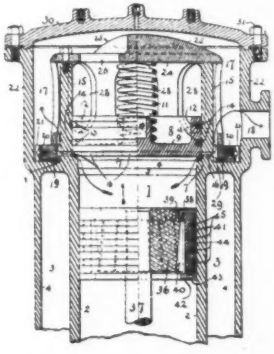
668,354. PNEUMATIC IMPACT - TOOL. Samuel Oldham, Frankford, Pa. Filed Nov. 2, 1900. Serial No. 35,218.

668,375. AIR-SHIP. Aristarchus F. Hubbard, Simmler, Cal. Filed Aug. 11, 1898. Serial No. 688,353.

668,398. PNEUMATIC TIRE FOR WHEELS. John Adair, Waterford, Ireland. Filed July 17, 1900. Serial No. 23,965.

668,405. PNEUMATIC PUMP. Daniel L. Holden, New York, N. Y. Filed May 19, 1900. Serial No. 17,208.

A pneumatic pump or compressor, a pump-barrel having an open end and thereto attached an elarged cylinder, a piston-valve seated at the end of the barrel and within the cylinder, ports opening through the cylinder and above the piston-valve seat, a chamber exterior to the cylinder and valves within the chamber, surrounding the cylinder, adapted to yield to pressure from within the cylinder and open the ports, and means to press the valves to their seats and close the ports upon the cessation of pressure from within the cylinder.



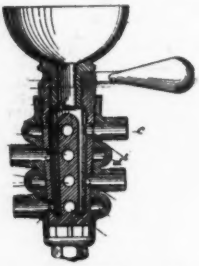
A pneumatic pump or compressor, a pump-barrel having an open end and a valve seated thereon, ports opening outward from and above the valve-seat, an angled check-valve seat at the outer end of the ports having its lower and outer end terminating in a curve, check-valves upon the angled seats, entering the curved end of the seat and guided thereby for swinging movement, and means to force the valves to their seats.

668,613. AIR-BRAKE. Niels A. Christensen, Milwaukee, Wis. Filed June 12, 1899. Serial No. 720,139.

668,733. PNEUMATIC TIRE. Phares S. Griffith, Grand Rapids, Mich., assignor of one-half to Rose Bachman, same place. Filed June 1, 1900. Serial No. 18,778.

669,065. COMPRESSION - LUBRICATOR. Wilhelm Michalk, Deuben, near Dresden, Germany. Filed March 28, 1900. Serial No. 10,569.

In the device of the character set forth, the combination, with a suitable casing, of a series of nozzles on said casing adapted to be connected with the oil-passages from the several cylinders of the lubricator, and a series of nozzles adapted to be connected with the oil-passages conveying oil to the parts to be lubricated, of a rotatable body in said casing, a series of horizontal perforations in same, adapted to register with the said oil-pasages, a series of vertical perforations adapted to be connected with the oil-passages from the lubricator-cylinders, and a common filling vessel arranged above the rotatable body and communicating with the vertical perforations.



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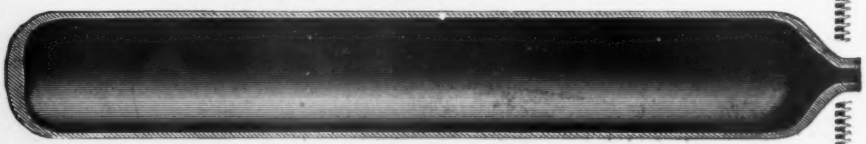

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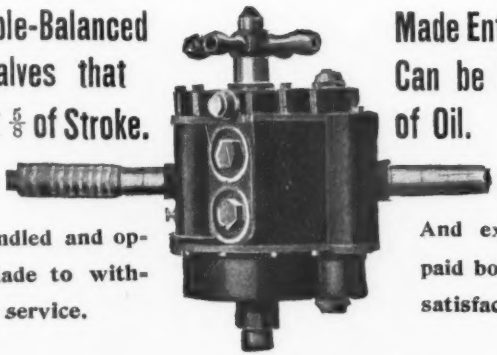

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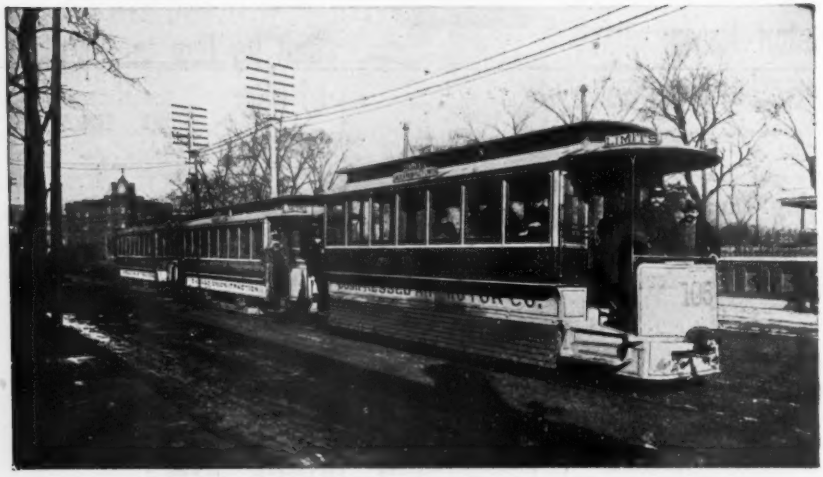

The above cut is of a 28 foot Compressed Air Motor Car hauling two trail cars in Chicago.

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Total round trips, . . .	37,408
Total mileage, ...	205,744
Total passengers carried,	2,201,235

Average number of miles per car per day, 95.
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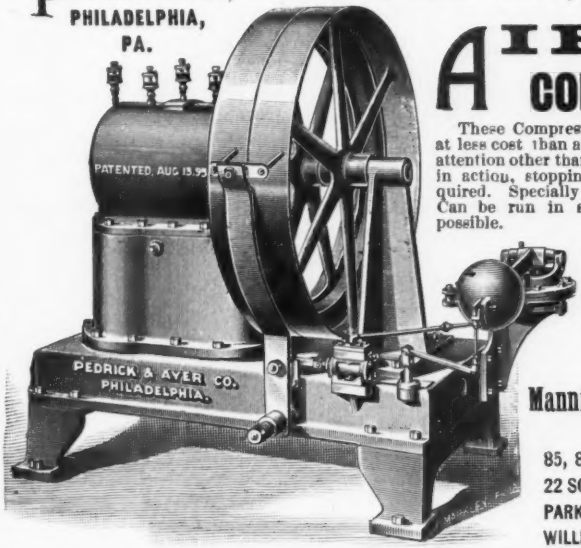

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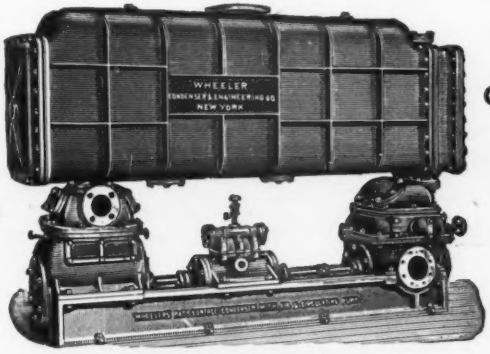

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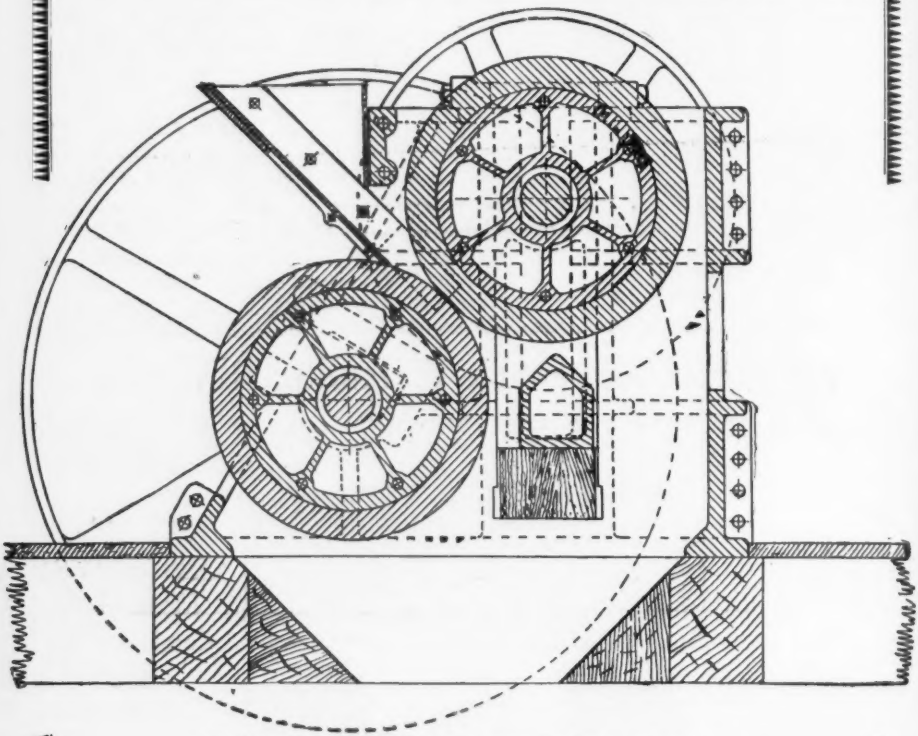

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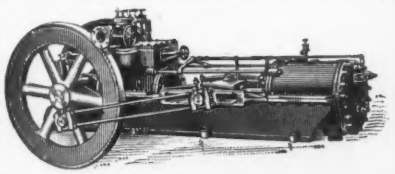

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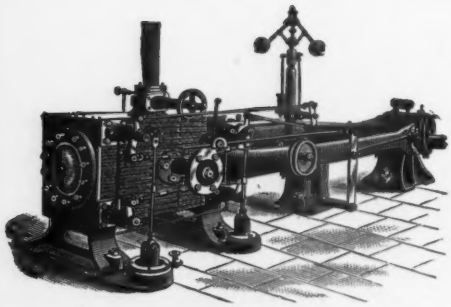

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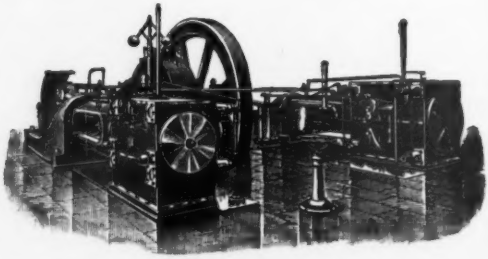

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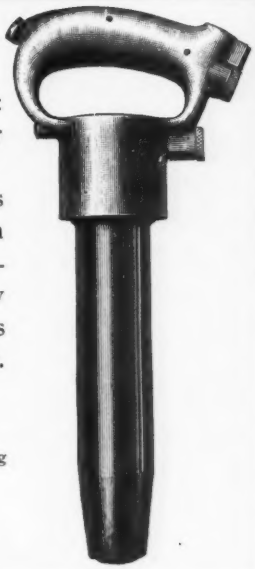

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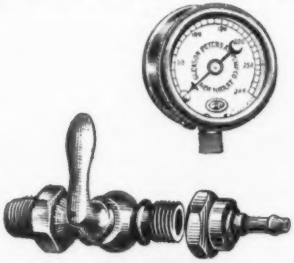

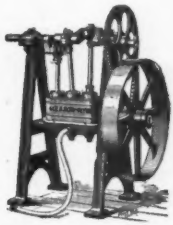

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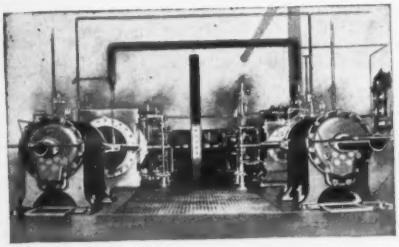

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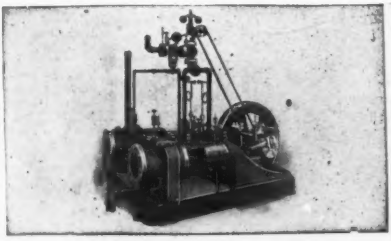

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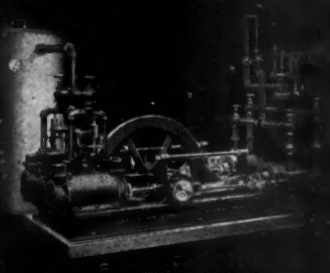

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